GENERAL MOTORS

ENGINEERING JOURNAL

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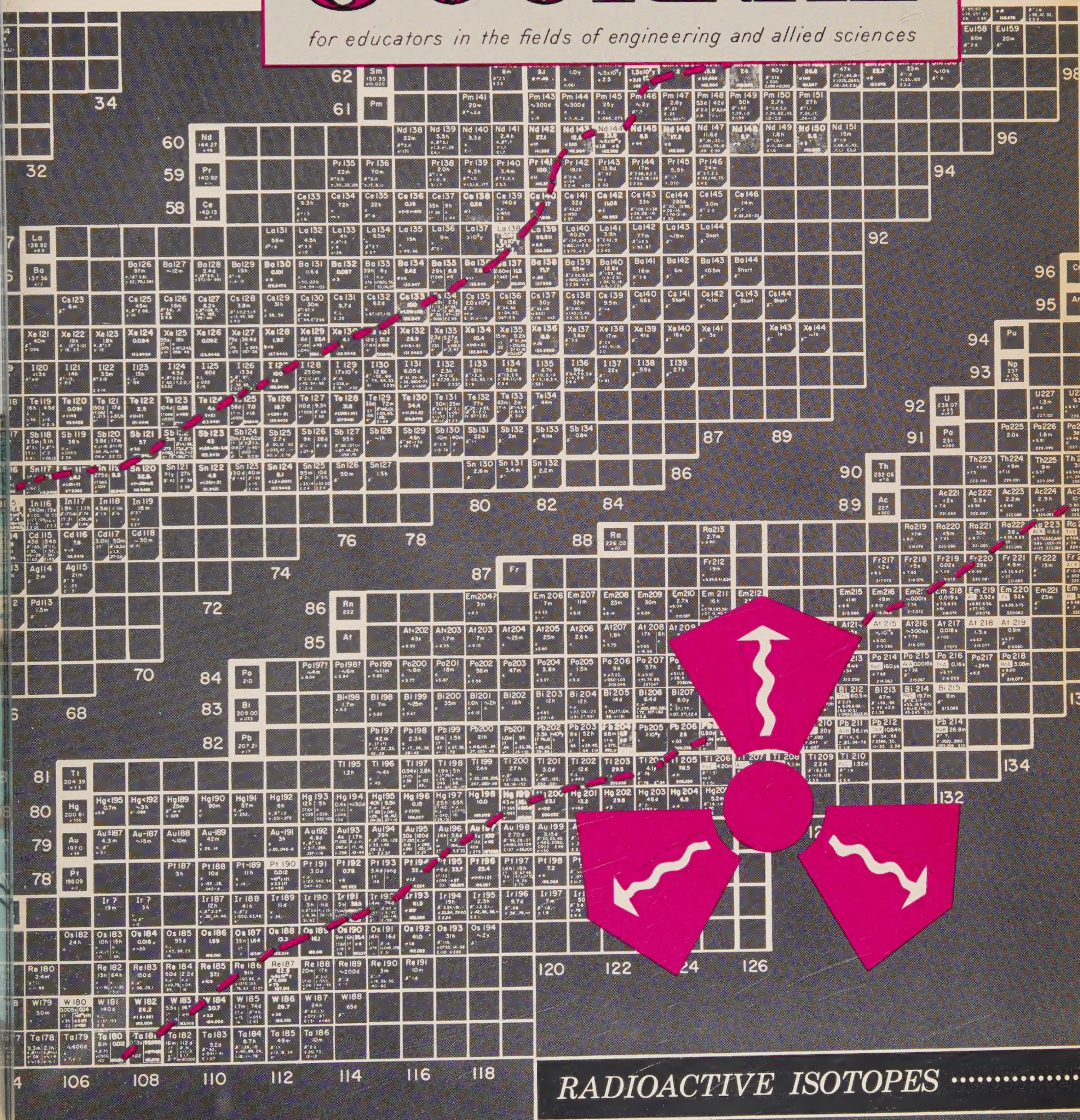
for educators in the fields of engineering and allied sciences



RADIOACTIVE ISOTOPES ....

On Basic and Applied Science

Determining the proportions of basic and applied science is not particularly a new problem in industrial research laboratories. But some new light has been thrown on this problem in recent years because of a change in research philosophy which occurred following World War II.

The change began with a healthy disillusionment. Immediately after the war it seemed that science and what it could do was "discovered" for the first time by some people. Science appeared to get confused with magic. For awhile, anything promised in the name of science was accepted as already accomplished fact. Scientists were hired and were expected to produce miracles on guaranteed delivery schedules. There was the mistaken notion that the "crash" methods so successful on engineering problems during the war could in some manner be applied to science.

Fortunately, this disillusionment was safely passed and what remained was a better understanding of what can be done and what cannot be done in the name of science.

Some companies found that while they might have acquired scientific talent and research facilities beyond their short range needs, the long range benefits of this talent were enormous. Companies which formerly considered research a luxury now consider it a necessity. The result has been a much wider distribution of scientific talent that is at a remarkably high level. Furthermore, industrial companies today, instead of maintaining their research in the hope that "something good" will come of it, support an organized research *program* with definite objectives and responsibilities which will provide for the growth of the company.

With such a philosophy diffused throughout industry today, administrators of research have to decide the question: "How much of the program will be devoted to long range research, or basic science, and how much to short range research or applied science?"

The exact ratio of basic to applied science cannot be fixed by formula. It varies with the past history of the company, its financial condition, and the competitive situation. However, since a company is itself one of society's mechanisms specifically designed to provide an incentive to develop new products, we might think that a general rule would be: "As long as there are more novel ideas to exploit than the organization can digest effectively, the basic or exploratory type of activity need not be emphasized. When the novelty of ideas begins to slacken, it is time for a campaign of basic science to provide new areas for advances."

Basic science, however, cannot be turned on and off like a kitchen faucet. Although the time between the scientific discovery and its application in a useful device has grown progressively shorter, we do not know how to reduce the time to make the scientific discovery. Research can be depended upon to come up with a solution in a hurry only when it has a backlog of fundamental knowledge provided by a continuing program. For this reason, the prudent research administrator maintains his basic research program at a level which in his judgment he can justify as a continuing, long-term activity.

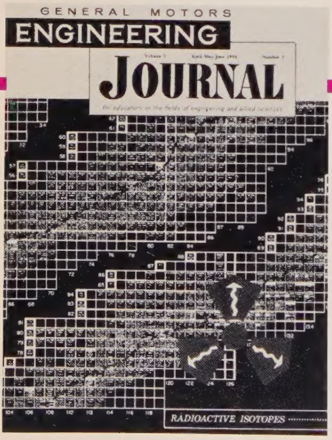
The value of a proper ratio of basic to applied science was demonstrated in America's progress in the field of atomic energy. In the 1920's and 1930's a very considerable background of so-called "useless" scientific information was acquired regarding the atomic nucleus. When the scientific "discovery" of the fission process came, all of this information was available for application. The remarkably rapid development of atomic energy both for military and civilian uses was the result.

In the case of General Motors research activities, our studies in fundamental fields such as friction, materials, energy, electronics, and atomic nuclei have provided knowledge which is applicable to our work in developments such as high compression engines, gas turbine and free-piston engines, instrumentation, and industrial uses of radioisotopes.

A sophisticated philosophy on scientific research pervades most industrial companies today. There is general agreement that the research program as a whole must be directed and it must include some selected ratio of basic science to applied science. As a result, there is both a wider distribution and a higher quality of industrial research talent and facilities. And such talent is a priceless national asset in the face of the special kind of threats that can be foreseen today.

L. R. Hafstad

L. R. Hafstad
Vice President in Charge
of Research Staff



THE COVER

This issue's cover design, by artist Richard P. Renius, directs attention to the ever-increasing importance of radioactive materials in industry today. A portion of the Chart of the Nuclides is used as a background for the well known laboratory symbol for radioactivity. The complete Chart of the Nuclides describes over 1,200 different stable isotopes, artificially produced isotopes, and naturally radioactive materials. The line of greatest stability, shown as a dotted line on the chart, marks the line of the most stable nuclei. Isotopes along this line have a mass-energy relationship which gives them the highest binding energy per nucleon. Isotopes on either side of the line have a greater tendency to be radioactive. The Chart of the Nuclides was prepared by the Knolls Atomic Power Laboratory, which is operated for the Atomic Energy Commission by the General Electric Company. The Chart enables scientists to choose the correct isotope for a specific job.

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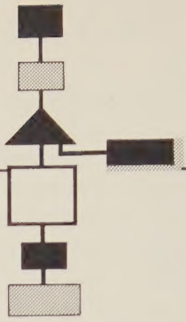
What Is a Digital Computer?



By **DONALD E. HART**
General Motors
Research Staff

Electronic digital computers free engineers from time consuming calculations

Within the last decade the tools of engineering computation have progressed from slide rules and desk calculators to the modern electronic data processing machines. The remarkable speed of the new computers has opened new areas for engineering research. Instead of expensive and non-comprehensive experimental design methods, engineers now can produce a design by calculation, which formerly was impossible because of the great amount of time and paper work involved. Digital computers can perform complex arithmetical computations because of their ability to select and manipulate data from stored information. As a result, they have become very important engineering tools in the struggle to reduce the time between initial conception and final production of a design.

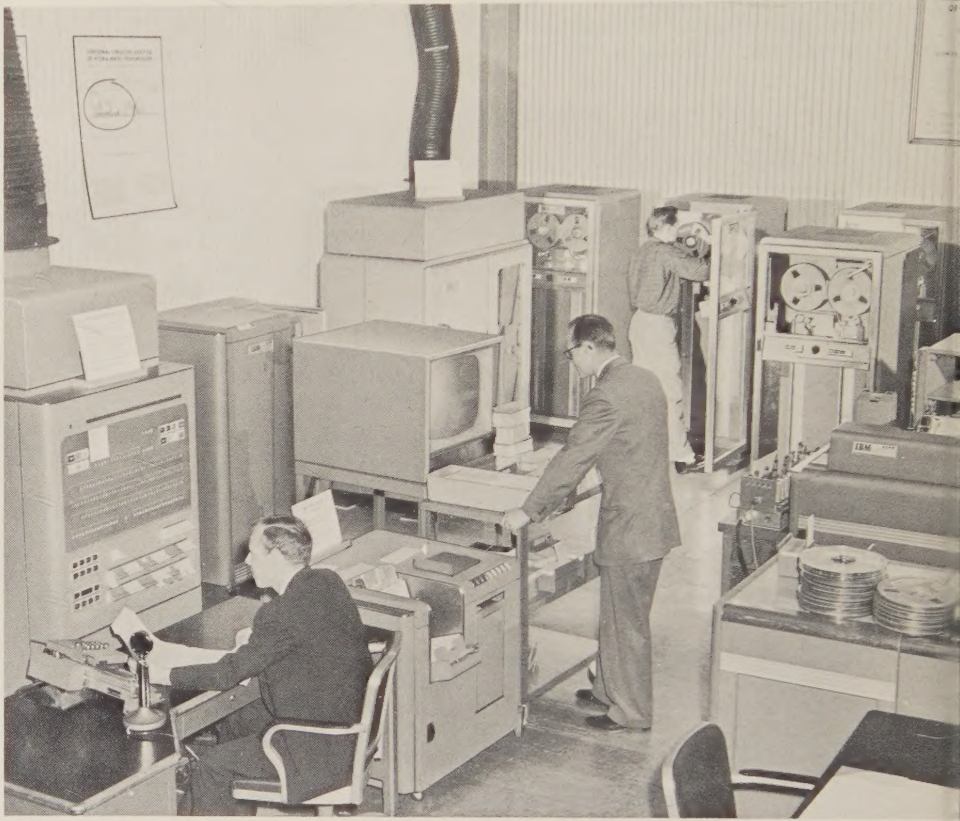


Fig. 1—The IBM 704 Electronic Data Processing Machine used by the GM Research Staff is a large-scale digital computer with a magnetic core memory (not shown). The operator in the left foreground is seated at the control console. To the right of the console is a cart containing decks of punched IBM cards which are used as input to the computer. In the left background an operator is mounting a reel of tape on one of the magnetic tape units used for input and output. Computer output also can be fed to a cathode ray tube mounted in a cabinet similar to a television set. Results can be displayed on the tube in graphical form for visual observation or photographic recording.

A LARGE part of engineering work is occupied by calculations and the processing of data, which are necessary to fully evaluate proposed designs, methods, and test results. Slow methods of calculation and data processing slow down the overall engineering project. In some instances the mountainous pile of calculations either prohibits engineers from beginning a project, or forces them to evaluate their results and base their findings on incomplete, non-comprehensive data and calculations.

Engineers have always sought methods and devices to speed up their calculations and data processing. The effectiveness of a given number of engineers is greatly increased by calculating devices which cut the time spent on a project and permit thorough investigation of all possible data.

The most recent devices to be applied to engineering calculations are the analog and digital computers, successors to the slide rule and desk calculating machine. The main difference between digital and analog computers is that the former calculates by counting, while the latter operates by measuring.

With the analog computer it is possible, in effect, to wire up electronic circuitry to behave mathematically like the physical system under study. By performing measurements on the electronic circuitry, it is possible to determine the behavior of the equivalent physical system. An analog computer is a combination of electronic circuits which are organized so that they can be wired together easily to simulate a physical system.

Digital Computers Are Readily Adaptable to Engineering Work

Digital computers operate by performing the arithmetical processes of addition, subtraction, multiplication, and division. They are widely used for both business and engineering applications. The basic difference between business and engineering usage is that in business the input and output of data is large, while the calculation by the machine is small. In engineering applications the calculation process is usually large and the amount of data input and output is small.

The function of a digital computer is to take in information, perform a calculation or arithmetical operation, and produce the modified information in a readable form.

A typical digital computer (Fig. 1) consists of five basic component units: input; storage or memory; arithmetic; output; and control. The input unit is the receiver of prepared information. This information must be in a form which the machine can "read." It must be in a physical form which the computer can handle, such as punched paper tape or cards.

The storage (memory) unit contains apparatus which retains the information for future reference. The machine must be capable of "remembering" thousands of bits of information to which it can refer during calculations.

The computer uses the information it has stored in its memory unit in arithmetical and logical operations performed in the arithmetic unit. This unit performs the addition, subtraction, and other operations to give the conclusions, which are produced by the output unit in readable form. The control unit controls the sequence of operations in the computer.

The Problem Must Be Prepared for the Machine

Before a problem can be solved by a computer, much preliminary work must be done to prepare the problem for the machine. Out of the seven following steps which are necessary to solve a problem on a digital computer the first five must be completed before the actual computation begins:

- *Mathematical formulation*—the problem must be described in mathematical language
- *Mathematical analysis*—the mathematical formulae must be reduced to a numerical form suitable for machine use
- *Programming*—the complete logical flow of the problem solution must be established
- *Coding*—the detailed sequence of instructions to the machine must be written down in the specialized machine language
- *Checkout*—a test problem with known answers must be run on the machine to assure the correctness of the coding
- *Production computation*—the actual computation of the problem can be run only after the correct set of instructions has been given to the machine
- *Evaluation of results*—the results of all machine computation must be viewed in the light of the physical situation which is being studied.

The use of the digital computer can be illustrated by following through, in detail, the steps involved in solving a simple problem, such as finding the lengths of the sides of a rectangle that has a given area.

The Problem

Given: A rectangle with an area of A sq in.
One side is n in. longer than the other side.
Find: The length of the sides.

Mathematical Formulation

The problem first must be described in mathematical language as follows:

$$x\,(x + n) = A$$
$$x^2 + nx - A = 0.$$

This is recognized to be the form of a quadratic equation. Since a certain amount of effort is to be expended in preparing this problem for computer solution, it is desirable to set up the following routine which will solve any quadratic equation:

$$ax^2 + bx + c = 0$$

where, in this case,

$$a = 1$$
$$b = n$$
$$c = -A.$$

Mathematical Analysis

This step is necessary to reduce the mathematical formulae to numerical forms suitable for machine solution. If numerical values are given for a, b, and c in the quadratic, the values of x cannot be found directly.

If the quadratic can be manipulated into the form

$$x^2 + 2rx + r^2 = (x + r)^2,$$

the square root can be extracted, leaving only the first power of x. When this is done, the following familiar expressions are found:

$$x_1 = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$
$$x_2 = \frac{-b - \sqrt{b^2 - 4ac}}{2a}.$$

By inserting numerical values for a, b, and c, it is possible to find the roots of the quadratic.

Programming

Programming is the development of the complete logical flow of the problem solution. It must take into account the available information, what result is sought, and any restrictions in the problem. In the example, the following factors are present (Fig. 2).

Given: a, b, c
Find: x_1, x_2
Restriction: interested only in real roots.

Coding

It is now possible to write down, in the specialized language of the computer, the detailed sequence of instructions for solving the problem.

Two paper sheets (Table 1) are used in coding. They are called the *data* and *instruction* sheets. On the data sheet are recorded input data, final results, intermediate data, and numerical constants. On the instruction sheet are recorded the instructions to the machine, such as where to obtain a number (what section of the memory unit) and what operation to perform on the number. The lines on

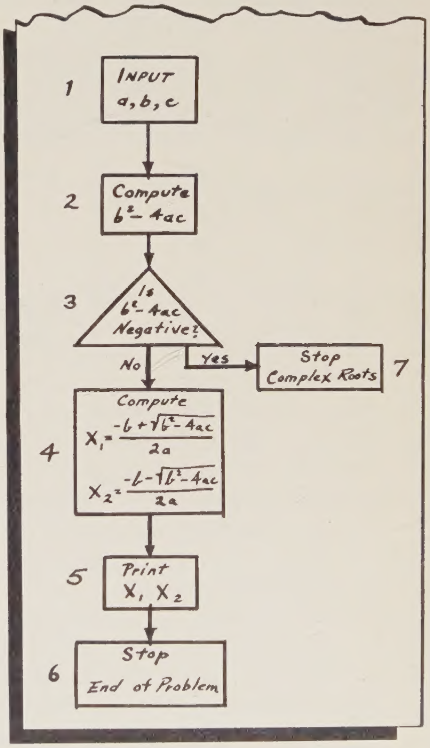


Fig. 2—This diagram illustrates the programming necessary for the solution of a quadratic equation. The computer receives the information a, b, and c, and then follows the sequence shown in steps 2 through 7 to produce the information x_1 and x_2.

the data and instruction sheets are numbered to correspond with locations on the memory unit of the computer.

On the *data* sheet the numerical values of a, b, and c are recorded on lines 100 through 102 (memory address 100 through 102). At the completion of the problem, the values of x_1 and x_2 are recorded on lines 103 and 104. Intermediate results, as they are developed, are recorded sequentially starting on line 105.

On the *instruction* sheet the numbers in parentheses in the right column refer to the corresponding numbers in parentheses in Fig. 2. Assuming that the computer is reading punched cards, the instruction on line 000 says, "Read the first card and record its information on line 100." This places the value of a in the computer's memory unit at address 100. Three cards are read in sequence, placing a, b, and c in the computer's memory. The instruction on line 003 says, "Take the information from line 100 (a), multiply it by the information from line 102 (c), and store the result (ac) on line 105." The instructions on lines 004 through 006 are executed sequentially to complete the computation of $b^2 - 4ac$. The instruction on line 007 asks, "Is the number on line 108 negative?" If the answer is no, go on to the next instruction in the sequence (008). If the answer is yes, the next instruction to be executed is located on line 018. The instructions on lines 008 through 014 are carried out in sequence to complete block (4) of the flow diagram (Fig. 2). This completes the arithmetic part of the computation.

The instruction on line 015 is to print the number on line 103 (x_1). To complete the problem, line 017 instructs the machine to stop. The instructions numbered 000 through 018 and the three numerical constants on lines 020 through 022 completely describe this problem to the computer. These 19 instructions and three constants constitute what is known as the computer program.

Checkout

Checkout is necessary to assure correctness of the coding. This is done by presenting to the computer a test problem to which the answers are known.

First, the program must be stored in the memory of the computer. One card is punched for each instruction. In the example, these cards contain the information from columns 1 through 5 of the instruction sheet (Table 1). There will be 19 instruction cards. Similarly, the numerical constants from lines 020 through 022 are punched into three cards from the first two columns of the data sheet. These 22 cards constitute the *program deck.*

If this program deck is inserted into the card reader of the computer and the *load* button is pressed, the computer reads the cards in sequence and stores

DATA SHEET

Line Number	Contents	Explanation
100	a	Input Data
101	b	
102	c	
103	x_1	Final Answers
104	x_2	
105	ac	Intermediate Results
106	4ac	
107	b^2	
108	$b^2 - 4ac$	
109	$\sqrt{b^2 - 4ac}$	
110	$-b$	
111	$-b + \sqrt{b^2 - 4ac}$	
112	$-b - \sqrt{b^2 - 4ac}$	
113	2a	
.	.	
.	.	
.	.	
.	.	
.	.	
.	.	
020	4	Numerical Constants
021	0	
022	2	

INSTRUCTION SHEET

Line Number	First Number	Operation	Second Number	Result	Explanation
000		READ		100	a into 100
001		READ		101	b into 101 (1)
002		READ		102	c into 102
003	100	MULT	102	105	ac
004	105	MULT	020	106	4ac (2)
005	101	MULT	101	107	b^2
006	107	SUB	106	108	b^2-4ac
007	108	NEGATIVE?		018	If yes goto 018 (3)
008	108	SQRT		109	$\sqrt{b^2-4ac}$
009	021	SUB	101	110	$-b$
010	110	ADD	109	111	$-b+\sqrt{b^2-4ac}$
011	110	SUB	109	112	$-b-\sqrt{b^2-4ac}$ (4)
012	100	MULT	022	113	2a
013	111	DIV	113	103	x_1
014	112	DIV	113	104	x_2
015	103	PRINT			print x_1 (5)
016	104	PRINT			print x_2
017		STOP			end of problem (6)
018		STOP			error (7)

Table 1—The Data Sheet and Instruction Sheet shown here indicate the coding, or detailed sequence, of the computer for solving the example of the quadratic equation (Fig. 2). The line numbers on the two sheets correspond to the information's *address* on the computer's memory unit.

the information from each card into a memory location corresponding to the line number punched in the cards. Thus, the instruction from line 003 of the instruction sheet is stored in memory cell 003 in the computer. The number associated with each memory cell is called its *address*.

Three cards containing numerical values of *a*, *b*, and *c* are placed into the card reader. The computer is told that the first instruction is in memory cell 000 and the *start* button is pressed. The computer executes the first instruction which causes the contents of the first data card to be stored in memory cell 100. The computer then receives the next instruction from memory cell 001, and continues in sequence until the problem is completed.

If the computer results do not agree with the known answers, corrections must be made in the program until the computer produces the correct results. Another test also must be made to verify that the computer operates correctly when the roots are complex.

At this stage in a larger problem, checks also would be made of the correctness of the flow diagram, the accuracy of any numerical approximations made in the mathematical analysis step, and the adequacy of the initial mathematical approximation to physical reality developed in the mathematical formulation step.

Production Computation

A digital computer is a general purpose device which is potentially capable of performing any mathematical operation. Until it receives a set of instructions, however, it can do nothing. The process of reading a set of instructions into the memory unit converts a general purpose computer into a special purpose device which is immediately available to solve a particular problem, in this case a quadratic equation (Fig. 4).

Although a computer would never be used to solve one quadratic at a time, it would be used if there were many sets of input data. The original program can be made to do this by replacing the stop instruction (line 017) with this instruction: GOTO 000, which tells the computer to get its next instruction from line 000. This provides continuous operation.

Evaluation of Results

The results of all machine computation must be viewed in the light of the physical situation under study. If the test problem run in the checkout was:

$a = 1$
$b = n = 6$ in.
$c = -A = -16$ sq in.,

the values for x_1 and x_2, therefore, would be

$x_1 = 2$
$x_1 + n = 8$
$x_2 = -8$
$x_2 + n = -2.$

It is apparent that only the first answer is reasonable, although both are mathematically correct.

Summary

This simple example demonstrates the important aspects of a digital computer. First, with a set of simple instructions large and complex problems may be solved. More complex problems may require several thousand machine instructions. Second, the computer is able to choose between two courses of action where the choice may be the result of previous calculations. By compounding these two-way choices, the computer can make complex decisions. A third factor is the tremendous speed of the computer. One model computer, for example, carries out 40,000 instructions per second. The combination of these three factors gives the computer a high degree of flexibility. Almost any problem which can be expressed mathematically can be solved. Also, a digital computer is extremely adaptable—it can be ready to solve a new problem in the length of time it takes to read a new set of instructions into its memory from punched cards or magnetic tape.

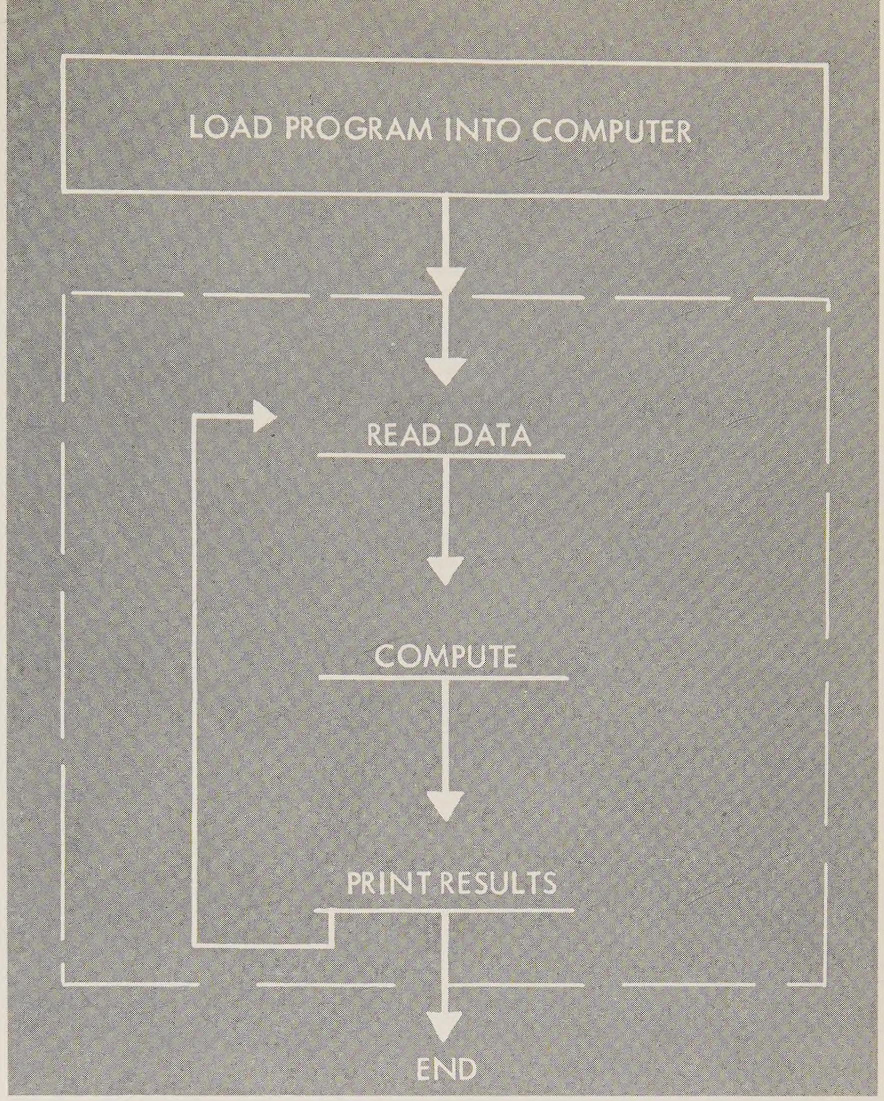


Fig. 3—This is a flow diagram of a typical production computation. The block formed by the dashed line represents a special purpose device, which results from loading a specific program into a general purpose computer.

Testing Paper Gas Turbines: Applying the Digital Computer to Engine Design

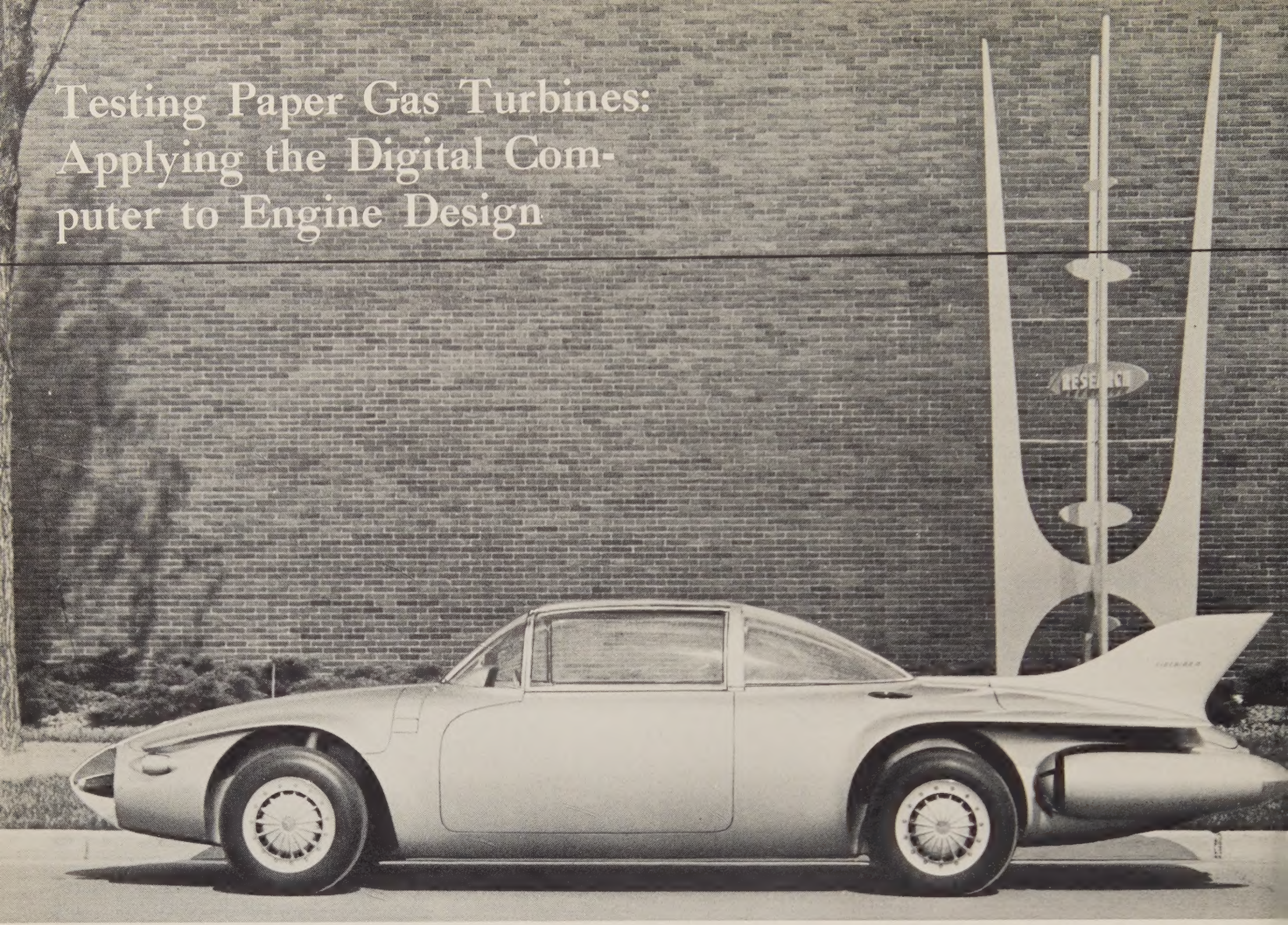


Fig. 1—The Firebird II, General Motors experimental gas turbine engine passenger car, is powered by an engine that was partially designed by a digitial computer. The car features a titanium body, all metal brakes, a central hydraulic system, and an air-oil suspension system.

The design of the Firebird II called for a new regenerative gas turbine engine. In the construction of this experimental car, GM Research Staff engineers applied the digital computer to the design of the engine. Using knowledge which had been gained from previous engine work on the computer, the engineers examined the capabilities of over 100 theoretical gas turbine engines on the computer. By this method they were able to produce a satisfactory engine without the expensive process of producing several prototype engines. Although the computer did not design a "perfect" engine, it narrowed down the possibilities of engine designs to one which was basically sound, and it eliminated unnecessary machine shop work on unsatisfactory designs.

When the decision was made by General Motors to build an experimental gas turbine engine passenger car, it also was decided to construct a regenerative gas turbine engine for the car. The time schedule for the new car, called the Firebird II (Fig. 1), allowed only 10 months for engineers to design and build the new engine.

Although the Engineering Development Department (formerly the Gas Turbines Department) of the GM Research Staff had built a non-regenerative gas turbine engine (the GT-302), the designing and building of the new engine presented a real challenge. The engine had to be compact enough to fit under the Firebird's hood, which is only 36 inches above the ground line. Also, the engine output had to compare with the power of current passenger car engines.

Prior to the commencement of work on the Firebird II engine, a program was being run on the IBM 701 digital computer to analyze the performance of gas turbine engine designs. It was called a part throttle program, since it analyzed engine operations over a load range from idle to full power. It was realized that the design analysis of a aas turbine, while easily accomplished, told only a small part of the story of engine performance for vehicular applications. A vehicle engine must operate over a wide range of conditions, such as idle, city traffic, hill climbing, and open highway. An engine design which appears good at design point is not necessarily satisfactory under all operational conditions. A systems analysis of the gas turbine engine, which would show the performance over a wide variety of operating conditions, was needed.

In essence, a number of paper engines were designed and their operation was checked for performance and economy. As many mistakes as possible were caught on paper before any chips were cut in the machine shop. The philosophy of this approach was to do as much cutting and trying as possible on paper in order to minimize cutting and trying on metal, which is much more costly.

By PAUL T. VICKERS
and CHARLES A. AMANN
General Motors
Research Staff

Digital computer speeds basic engine design and cuts expensive prototype experimentation

Engine Performance Expressed Mathematically for Machine Computation

All engine components (Fig. 2) had to be examined for individual operating characteristics, which affect the operating efficiency of the complete engine. A condition of correct operational balance had to be maintained among the engine components to assure equilibrium operation of the gas turbine engine (Fig. 3). The effects of component variations upon equilibrium operation had to be considered as variables in the mathematical formulation of the gas turbine engine design problem for the computer. Also, variations in pressure and temperature throughout the engine had to be studied and taken into account in the computation (Fig. 4).

The first question which had to be answered was whether or not performance of the components under all operating conditions could be expressed in equations for solution by the computer. The engineers who had the most experience with each of the components were asked about the ones on which they worked. For example, an engineer who was familiar with compressors was asked if he could write an expression which would describe how high the air temperature and pressure would rise if the compressor speed, inlet temperature, and weight flow were given. An engineer who worked on heat exchangers was asked to write expressions for the amount of heat an exchanger would extract from the exhaust gas and add to the compressor outlet air. Other specialists were asked to write expressions concerning the performance of the components with which they worked (Fig. 5).

It was found that each component could be adequately described. All that remained was to tie them together in a package and study the relationship of each component to the other.

Engine Designs Evaluated at Varied Operational Conditions

After mathematical expressions for component operations were formulated,

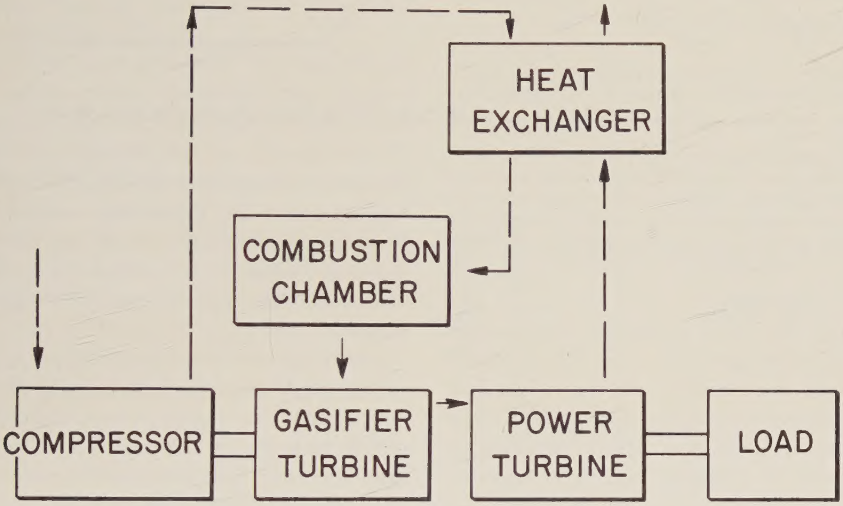


Fig. 2—This block diagram represents the various components used in the GT-304 engine (a regenerative gas turbine engine). Air enters the compressor, where its temperature and pressure are raised. It then flows through the heat exchanger, where heat is transferred from the exhaust gas to the high pressure air. After the hot air passes through the combustion chamber it enters the gasifier turbine, where it expands and its temperature and pressure drop. The energy which is extracted from the gas in the gasifier turbine is used to drive the compressor and some of the accessories. The gas is expanded still further in the power turbine, which is mechanically connected to the load (rear wheels of the vehicle) and mechanically independent of the gasifier section. The gas then flows out through the low pressure side of the regenerator, where most of the waste heat is extracted from the gas. This heat is transferred to the cold air prior to its entry into the combustion chamber, reducing the fuel consumption of the engine. Not shown on this drawing are the inlet silencer and exhaust duct, which must be considered in the performance of a vehicle engine. This block diagram represents a system of interrelated components, the performance of each component affecting the performance of all other components, and, hence, the overall performance of the engine.

1) GASIFIER TURBINE WORK = COMPRESSOR WORK + ACCESSORY WORK + BEARING LOSSES

2) TURBINE GAS FLOW = COMPRESSOR AIR FLOW - LEAKAGE FLOW + FUEL FLOW

3)
$$\frac{\text{AMBIENT PRESSURE}}{\text{COMPRESSOR INLET PRESSURE}} \times \frac{\text{COMPRESSOR INLET PRESSURE}}{\text{COMPRESSOR OUTLET PRESSURE}}$$
$$\times \frac{\text{COMPRESSOR OUTLET PRESSURE}}{\text{AIR SIDE OUTLET PRESSURE}} \times \frac{\text{AIR SIDE OUTLET PRESSURE}}{\text{BURNER OUTLET PRESSURE}}$$
$$\times \frac{\text{BURNER OUTLET PRESSURE}}{\text{GASIFIER TURBINE OUTLET PRESSURE}} \times \frac{\text{GASIFIER TURBINE OUTLET PRESSURE}}{\text{POWER TURBINE OUTLET PRESSURE}}$$
$$\times \frac{\text{POWER TURBINE OUTLET PRESSURE}}{\text{GAS SIDE OUTLET PRESSURE}} \times \frac{\text{GAS SIDE OUTLET PRESSURE}}{\text{AMBIENT PRESSURE}} = 1$$

Fig. 3—Three conditions are necessary for equilibrium operation of a turbine engine: (1) the gasifier turbine work must be equal to the sum of the compressor work, accessory work, and bearing losses; (2) the turbine gas flow must equal the compressor air flow, minus any leakage, plus fuel flow; (3) the product of all the pressure ratios throughout the cycle must equal unity. The first condition means that the only source of power for the compressor, accessories, and bearings is the gasifier turbine. If this turbine does not generate sufficient power, the compressor will decelerate. Conversely, when the turbine produces too much power, the compressor will accelerate. The second condition simply means that the engine can neither create nor destroy mass. The third condition means that no matter how many times the pressure varies in the engine, the pressure at the outlet of the exhaust will be the same as the pressure ahead of the inlet, since air is drawn in from and exhausted to the atmosphere. These three equations must be satisfied for all stable operating conditions of the engine.

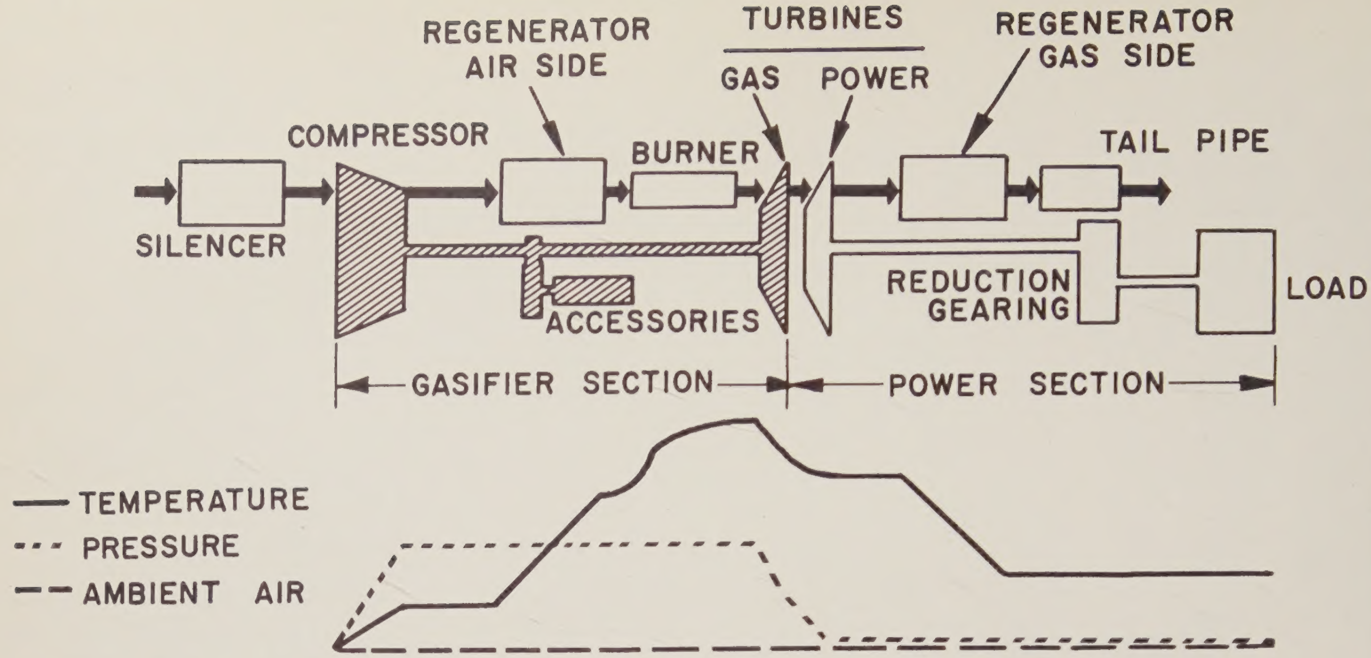


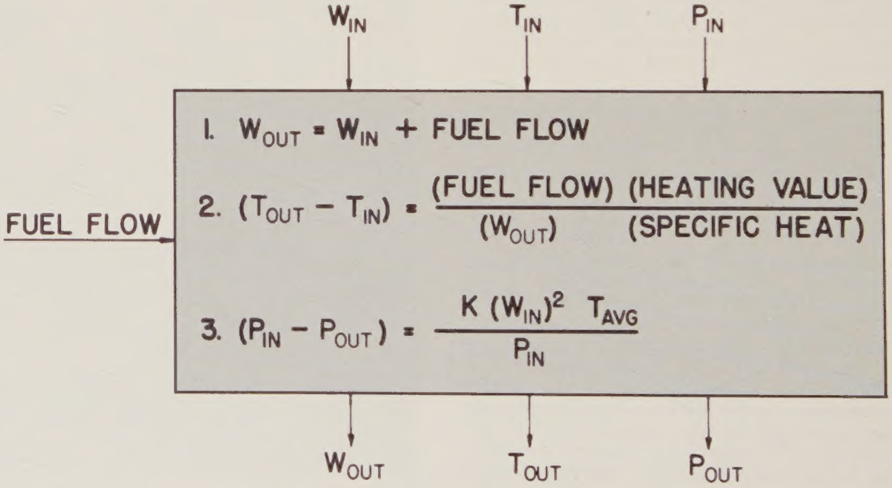
Fig. 4—In this block diagram of a regenerative gas turbine engine, the flow of gas is from left to right. The variations in temperature and pressure are shown on the lower curves. The temperature curve rises to the highest scalar value. The principal fact to be gleaned from the diagram is that within each component the weight flow, gas temperature, gas pressure, or any combination of two or three of these variables can change. The degree to which each of these variables is affected as the gas passes through defines the performance of that component.

the computer could solve the problem of determining the operational characteristics of engines using different components. For each engine design, calculations were made over a wide range of engine speeds. In each calculation a particular engine rpm to be investigated was selected, and an educated guess at weight flow, temperature, and pressure throughout the engine was made. Using these assumptions the pressure loss in the inlet duct, the pressure and temperature rise in the compressor, the pressure loss and temperature rise through the air side of the regenerator, the pressure loss and temperature rise in the combustion chamber, the pressure loss and temperature drop through the gas side of the regenerator, and the pressure loss in the exhaust duct were all calculated.

Each calculation was checked to see if the three conditions necessary for stable operation were satisfied (Fig. 3). The second condition for equilibrium was automatically satisfied since no part of the engine either creates or destroys any of the mass which flows through it. To satisfy the third condition for equilibrium, the product of all the pressure ratios fore and aft of the turbines was set equal to the reciprocal of the ratio across the two turbines.

At this point additional information was called upon. The flow characteristics of the two turbines had been described to the computer, and earlier in the computation the digital computer had determined the pressure ratio split between the two turbines and derived internally an expression for this pressure ratio split (Fig. 6). The computer could then determine the pressure ratio across each turbine and the power output of each turbine.

Based on the initial guesses, the pressure, temperature, and weight flow throughout the engine were computed. These factors were not the same as those assumed initially. If they had been cor-



$$1.\ W_{OUT} = W_{IN} + \text{FUEL FLOW}$$

$$2.\ (T_{OUT} - T_{IN}) = \frac{(\text{FUEL FLOW})\ (\text{HEATING VALUE})}{(W_{OUT})\ \ (\text{SPECIFIC HEAT})}$$

$$3.\ (P_{IN} - P_{OUT}) = \frac{K\,(W_{IN})^2\ T_{AVG}}{P_{IN}}$$

Fig. 5—A simplified mathematical expression for the combustion chamber of a gas turbine engine consists, basically, of three equations. The first equation (1) relates the weight flow out of the chamber to the entering weight flow plus any loss or addition of flow. The second equation (2) equates the change in temperature to the factors affecting temperature in the chamber. The third equation (3) expresses the change in pressure level across the chamber. The mathematical approach to all gas turbine engine components is to start with the inlet conditions of weight flow, temperature, and pressure, and then calculate what happens to these parameters within the component. The results of such computation will be weight flow, temperature, and pressure out. Similar expressions were written for all components of the GT-304 engine, which made changing of the program easy. For example, if an idea for burning a new fuel arose, the mathematical model was updated by merely changing the heating value of the fuel in equation (2).

rect to start with, it would not have been necessary to do the problem. The computer then updated the assumptions and repeated the cycle until the pressures and temperatures agreed with the last previous calculation. At this point a check was made to see if the first condition for equilibrium was satisfied. That is, is the gasifier turbine generating too much, too little, or just the right amount of power to drive the compressor and accessories? If it is generating too much power, the compressor is accelerating and the first assumption of weight flow was too low. If it is decelerating the reverse is true. In either case a better guess at weight flow was made, and the whole iteration process repeated until all three conditions for equilibrium at that particular operating point were satisfied.

Then the next engine operating condition was chosen and the process repeated until a complete performance map of the paper engine in question was known. On the IBM 701 computer, obtaining the complete map took fifteen minutes. This compares to at least six man-months of desk calculating (if no mistakes are made before getting the final answer). This saving in time must be balanced against the tedious man-hours necessary to get this problem initially programmed for the machine.

After the part throttle program for the regenerative engine had been written, additional features were included to take out more of the bookkeeping and design computations for a particular engine. The following steps were added to the part throttle computations to complete the programming:

Block 1—thermodynamic cycle design, which established the design point of the engine

Block 2—regenerator design, which established the size of the regenerator

Block 3—scaling of the components for use in block 4, which, in a sense, assembled the particular paper engine to be tested

Block 4—evaluation of the design over the speed range in the part throttle program

Block 5—printing of the results.

One of the most important phases of any setup of this kind is establishing the degrees of validity of the answers. In other words, how good are the answers quantitatively? A comparison between test cell and computed part throttle engine performance for the GT-302 non-regenerative engine (Fig. 7) showed that the trends which were indicated by the computations for the GT-304 engine were correct and that the computed results agreed reasonably well quantitatively with the actual test results.

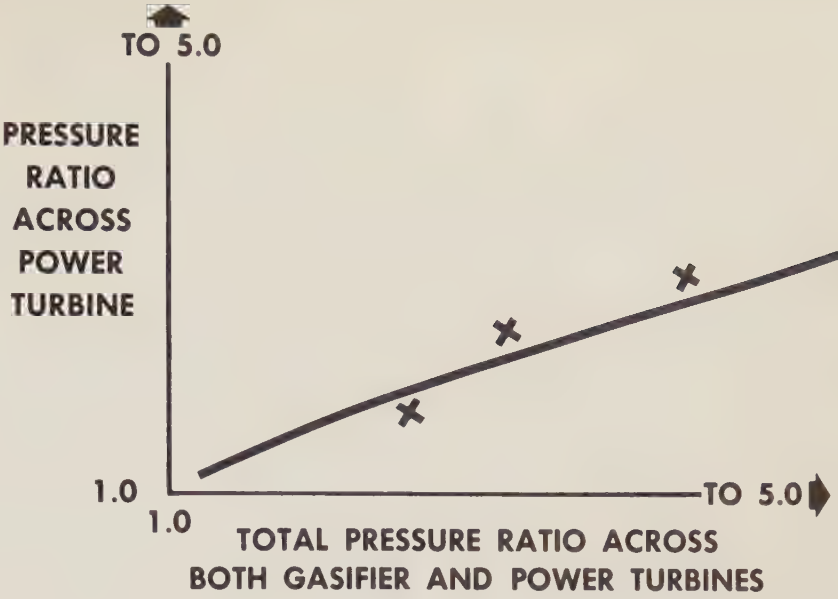


Fig. 6—Shown here is a comparison of the pressure ratio across the power turbine and the total pressure ratio across both the gasifier and power turbines.

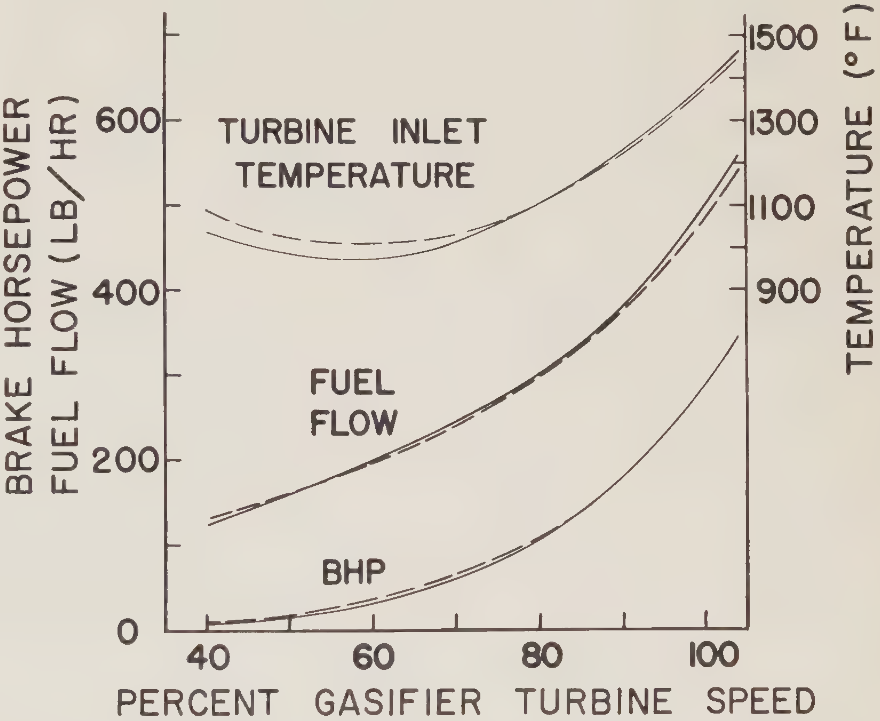


Fig. 7—To check if the computations for the GT-304 engine were headed in the right direction, a comparison was made between the predicted, or computed, performance (dashed curves) and the actual part throttle performance (solid lines) of the GT-302 non-regenerative gas turbine engine. The comparison indicated that the trend of computation on the GT-304 was correct.

Basic Questions in Engine Design and Performance Answered During Computation

After the machine was capable of performing the necessary calculations, over 100 paper engines were "tested" by the computer without cutting any metal. Many of the engines were variations of

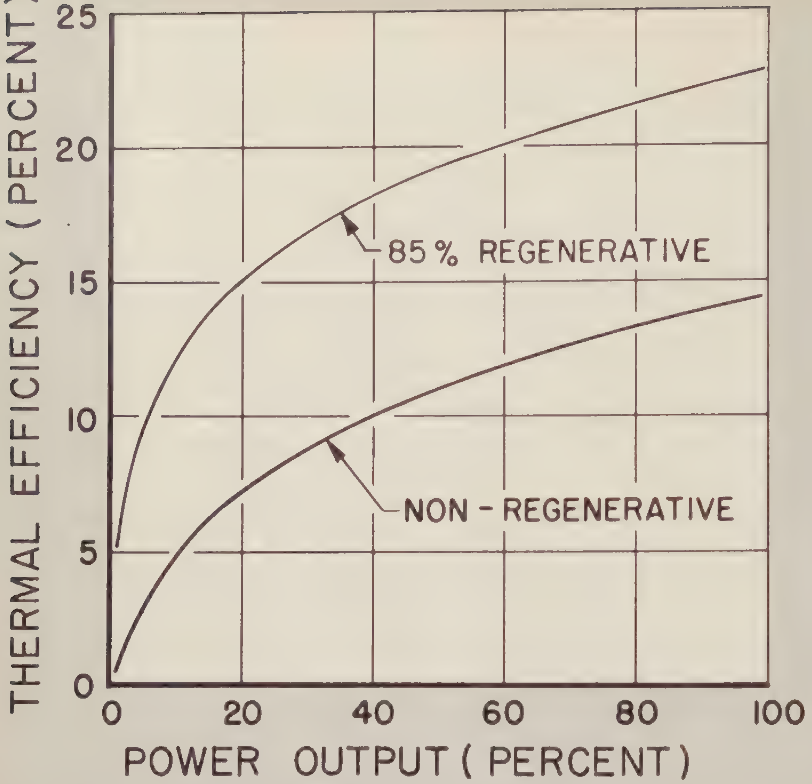


Fig. 8—A comparison of the thermal efficiencies of a regenerative and a non-regenerative gas turbine engine shows that a regenerative engine is more advantageous, especially at low power output.

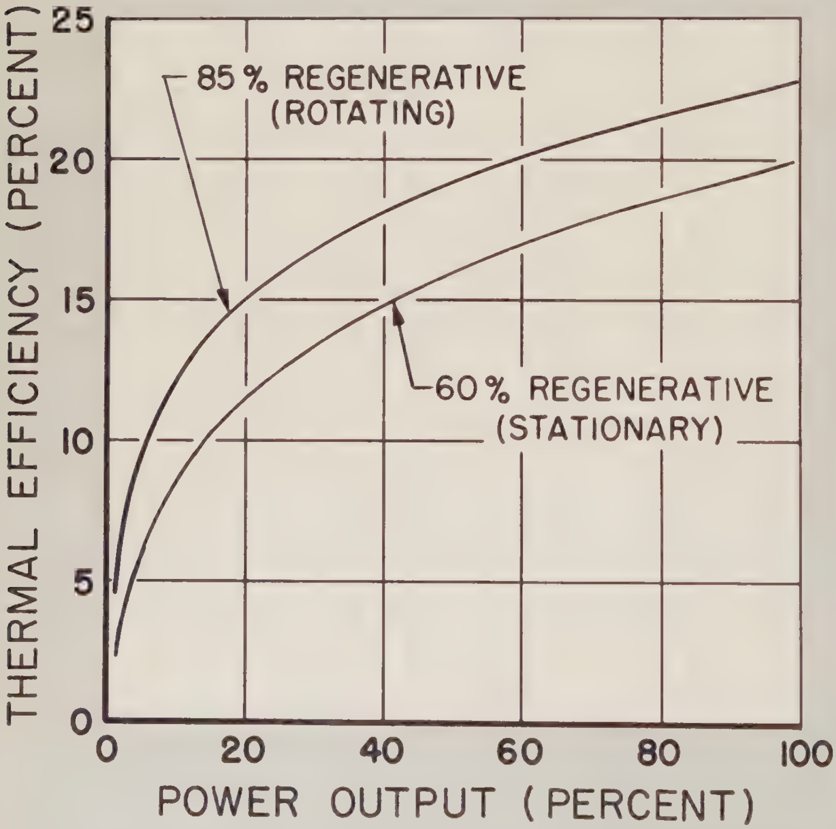


Fig. 9—Shown here is a comparison of the thermal efficiencies of two regenerative engines of equal size and power rating, one with a rotating regenerator and the other with a stationary regenerator. The curves indicate that despite the leakage occurring in the rotating regenerator it has the advantage of a higher thermal efficiency throughout the output range.

the same basic design. Several different problems concerning gas turbine engines were examined by the computer. One of these problems was created by the gasifier inlet temperature.

At gasifier turbine speeds of less than 60 per cent of rated rpm, the turbine inlet temperature starts to rise (Fig. 7). This increase in temperature is affected if heavy accessory loads are added to the gasifier turbine at low gasifier speeds. In the Firebird II the following load had to be driven by the engine: a 12-volt, 100-ampere generator; an oversize air conditioner (because of the bubble top); and a large hydraulic pump for the central hydraulic system, which included steering, brakes, and suspension.

All of these accessories had to operate at idle speed of the turbine. It was found that the increase in turbine inlet temperature at idle would be undesirable if they were driven by the gasifier turbine. Therefore, the design was arranged to drive the heavier accessories with the power turbine instead of the gasifier turbine.

Another of the original computations was an investigation of the benefits to be derived from a regenerative engine as compared to a non-regenerative engine. Also, if a regenerator was to be considered, what kind should be designed, and how much heat transfer would be required from it?

A comparison between thermal efficiencies of regenerative and non-regenerative engines (Fig. 8) showed that at design point (100 per cent) the regenerative cycle increased the thermal efficiency 60 per cent above that of the non-regenerative cycle. However, at 10 per cent power the increase was found to be 150 per cent of the thermal efficiency of the non-regenerative cycle. This indicated that the benefits from regeneration were even more pronounced at light loads.

The next problem to be investigated was the comparison of a rotating regenerator with a stationary regenerator. It was found that a higher percentage of effectiveness could be obtained with a rotating regenerator than with a stationary one of the same volume. However, the rotary regenerator had certain leakage losses which had to be considered in the evaluation of the cycle. The results of this study (Fig. 9) indicated that in spite of leakage the rotary regenerator held its advantage in higher thermal efficiencies throughout the operating range, and especially at light loads. Based on these and other results from the part throttle program the GT-304 engine was designed (Fig. 10).

Summary

Although the computer was used for such tasks as the aerodynamic and stress analyses of the compressor and turbines and the design of the heat exchangers, the creative design and mechanical arrangement of the power plant were done by engineering personnel, not by the computer. The fact that the test cell performance data agreed with the predicted results does not imply that the perfect engine was designed. As with any new engine concept, such things as thermal distortion problems and bearing temperature problems were present. The important fact to remember is that a considerable number of the 100 paper engines would not have operated successfully, and the engine design which evolved from the paper gas turbines was basically sound.

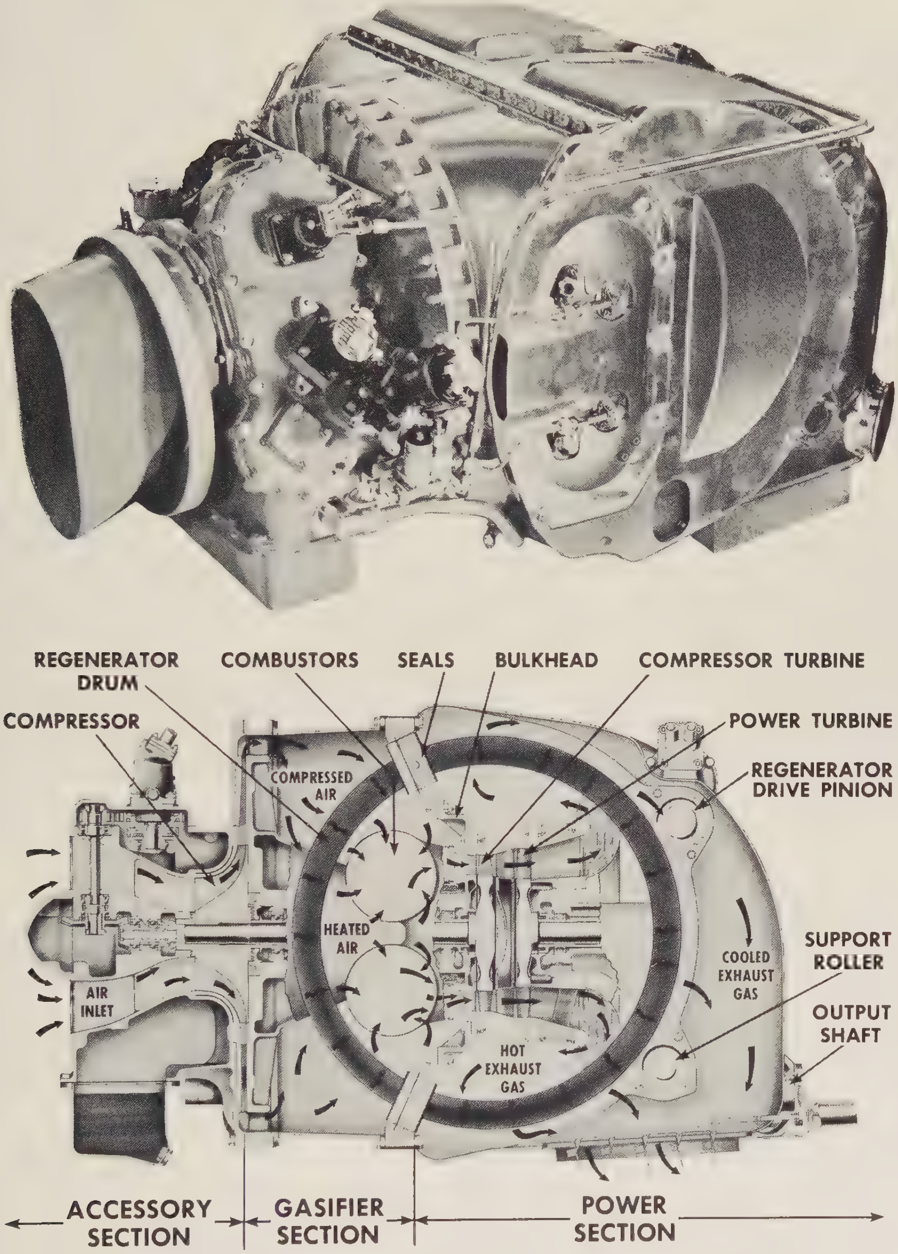


Fig. 10—The 200 hp, GT-304 engine (top) shows the relative size of the 200 hp package. The actual engine was tested in the Research Staff test cells, where the performance agreed substantially with what had been predicted by the computer. Shown at the bottom is a schematic cross section of the GT-304 gas turbine engine. Air enters the engine on the left, flowing through the air inlet into the compressor, where its pressure is raised. From the compressor diffuser it enters the air side of the regenerator, where its temperature is raised by heat recovered from exhaust gases. The air then enters the combustion chamber, where kerosene fuel is burned. The hot gas is expanded in the gasifier turbine, which drives the compressor and some of the accessories. The gas then enters the power turbine, where further energy is removed. The power turbine is mechanically connected to the reduction gear and the output shaft, which rotates at normal automotive speeds. After the gas leaves the power turbine, part of its kinetic energy is recovered in the combination exhaust diffuser and turning vanes. The gas then flows radially through the regenerator drum, giving up waste heat. The cooled exhaust gas leaves the exhaust collector at the bottom of the engine. The regenerator drum rotates at about 30 rpm in a plane perpendicular to the axis of rotation of the turbines.

The success of the gas turbine engine design problem resulted from following four rules which should be applied when using the digital computer as a tool for any kind of systems analysis. The four rules are:

- Start out early on the analysis (enough time must be allowed to develop and test the program for the computer)
- Set up the mathematical model by breaking down the system into components as simple and small as possible (in this way the system can be altered a small part at a time in a manner which is comprehendable)
- Rely on the specialist for each component to make engineering estimates of its performance ahead of time (a problem of this scope is definitely a team effort, not only in formulating the problem, but also in getting the equations into machine language)
- Above all, always keep in mind that the answers which the machine computes are only as good as the initial assumptions (keep an open mind and as more is learned about the individual components update the initial assumptions).

The gas turbine engine design demonstrates the kind of problem for which the digital computer is best suited; that is, it is a tool for doing the tedious time consuming computational problem. This problem was too large even to consider doing with the desk calculator, if a realistic timetable was to be met. It should always be borne in mind that the machine can basically do only the simplest kind of arithmetic, and make very simple decisions. It cannot think; it cannot create. The thinking and creating must be done by the engineer. Proper use of this tool should allow the engineer to do more thinking and creating and less of the tedious computing.

New Servo Controlled Simulator Measures Vehicle Ride and Roll

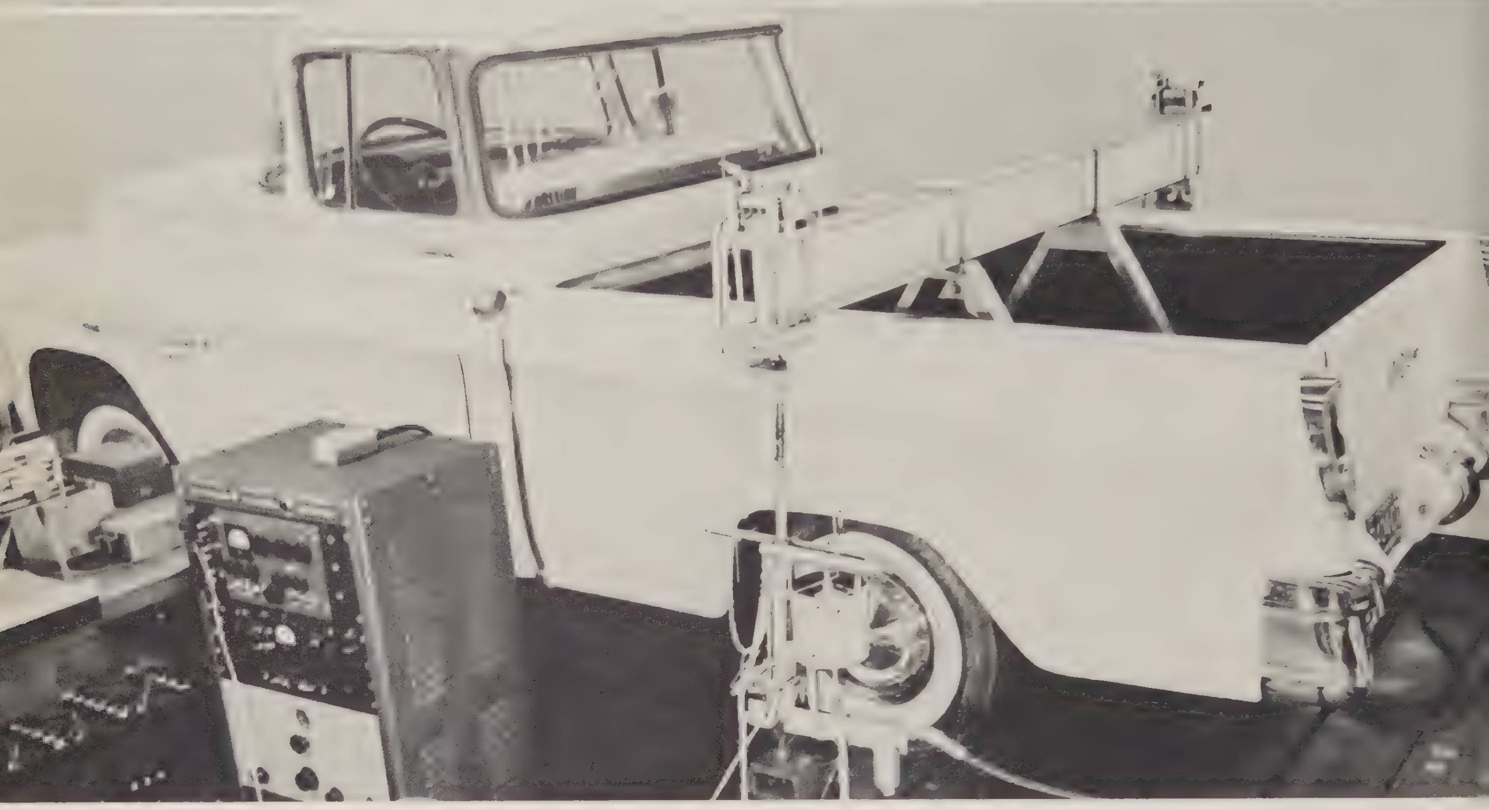


Fig. 1—Shown here is a pickup truck in test position on the new ride simulator for suspension testing.

The need for accurate and realistic laboratory methods for evaluation of ride performance and quality is always acute in the design of vehicle suspension systems. In an effort to fill this need, Chevrolet Motor Division engineers have developed a new simulator to test vehicle suspensions. The new simulator is driven by hydraulic cylinders, and is controlled by an electro-hydraulic servo valve system. The system enables engineers to simulate closely road tests in the laboratory, including such ride characteristics as *hop* and *tramp*. Another advantage of the machine is its operational ease and simplicity.

Ever since automobiles became accepted vehicles of transportation, automotive engineers have looked for ways to make them easier riding. Assuming that handling qualities are good, the ultimate test for car suspensions is rider comfort. No mechanical equipment or instrumentation is needed for this subjective evaluation. But, in attempting to improve ride quality, the need for accurate and realistic laboratory methods for evaluation of ride performance is always acute. Evaluation must be made by measuring what is going on during ride phenomena such as *hop* (wheels in phase) and *tramp* (wheels out of phase).

Methods to reproduce or simulate road conditions in the laboratory enable engineers to observe accurately the suspension components undergoing tests. The laboratory also provides closer control over testing conditions than the road does. This easy observation and close control of the testing permits engineers to check and improve their suspension designs more quickly and conveniently than they can on road tests.

In the past, the only way to study ride characteristics of automotive suspensions in the laboratory was to make a direct comparison of deflection characteristics. Curves were obtained by raising and lowering heavily weighted vehicles with hand jacks. The wheel deflections were read by eye on steel rulers, and the load was read from platform scales under each wheel.

The slow, laborious hand method of stroking to obtain load deflection information was considered adequate to a certain extent when steel springs were the only kind used. But this nearly static system was unrealistic and unreliable when viewed in the light of modern knowledge of road surfaces and the reactions of suspensions operating on these roads. The slow stroking revealed very little regarding vital factors, such as friction in the suspension (interleaf friction), and nothing as to how it changes with road speed and conditions. With the introduction of new spring media, such as rubber, gases, and liquids, testing

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Chevrolet Motor Division

Electro-hydraulic control provides new versatility in suspension testing

under conditions more nearly approaching those found on the road became mandatory.

Chevrolet engineers decided to construct a ride simulator to aid in testing vehicle suspensions. Before beginning their design, a list of performance specifications for the device was compiled. It was found that a suspension testing simulator should provide:

- Wheel travel of at least four inches in each direction from rest location
- Wheel motion at stroking speeds adjustable to 100 cycles per minute or more with the wheels either in phase (hop) or out of phase (tramp)
- Easy simulation of the load of a vehicle, so that it would be unnecessary to weight a vehicle to obtain load
- Easy measurement of forces and deflections and derivation of spring or suspension rates
- Automatic control of load and frequency, and manual control of deflection (manual control is needed to put a test vehicle slowly into its extreme position, so that deflections of members and clearance of parts can be measured and observed. Manual control is especially helpful in the case of rubber bushings loaded in two or more directions at the same time. Hand controlled power stroking can also be used to develop stress patterns on stress-coated parts, since the laboratory provides a much better controlled atmosphere than the highway)
- The ability to check the phasing of the left and right sides (when in parallel hop, both sides of the frame should be the same distance from the ground at all times. This is absolutely necessary when a roll bar is connected between the wheels, due to its load transfer action. In roll, the motion should consist of rotation about the roll axis of the vehicle, with no raising or lowering of the roll axis)
- Operational ease, so that the machine can be run by laboratory technicians.

Various methods of fulfilling these demands were explored to find the best combination of components. Although all seven of the major requirements were intimately related to each other, the required components could be placed in three categories: drive, control, and measurement systems.

Some Available Drive Systems Were Inadequate

Before deciding upon a drive system for the simulator, Chevrolet engineers examined several different kinds of systems. One device for exercising wheels at

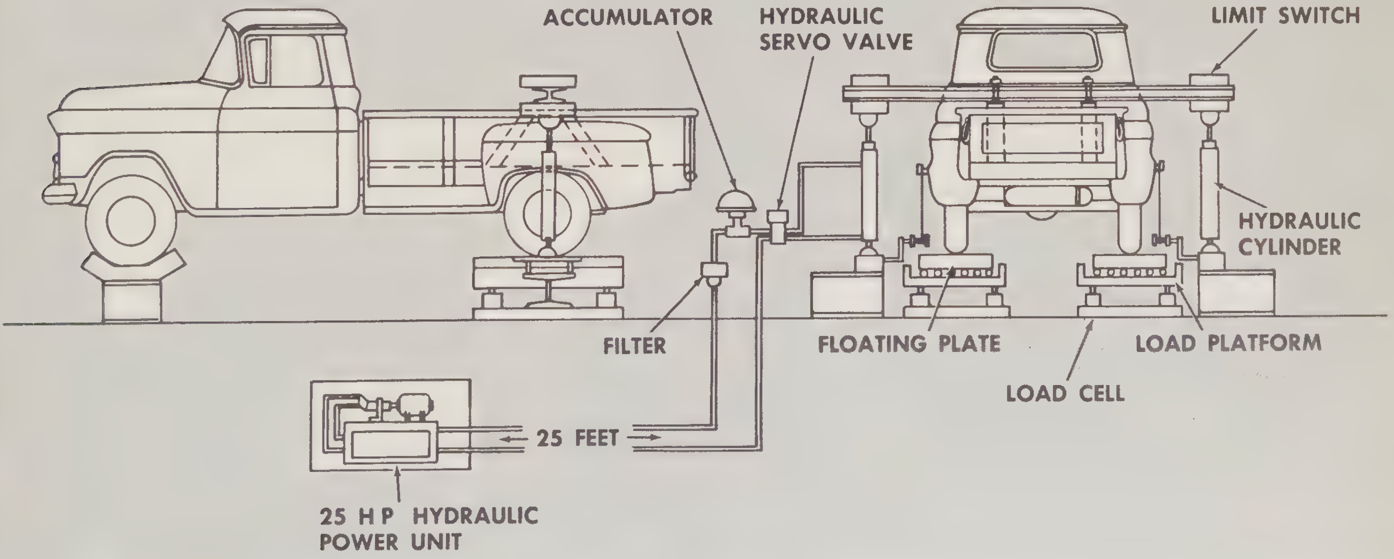


Fig. 2 (below)—The ride simulator uses a commercially available hydraulic power supply. A 25-hp electric motor is coupled directly to a piston pump, which delivers a constant 14 gpm flow of standard aircraft oil at a fixed pressure. A 20-gal oil sump tank is used as a reservoir, and is kept under 50 psi of air pressure for proper feed to the pump. To provide oil at a temperature under 120°F, a heat exchanger is located on the suction side of the pump.

Oil leaving the pump goes through an adjustable relief valve and a one-gallon accumulator mounted on the test stand. Just before entering each of the servo valves through a flexible line, the oil passes to a 10-micron filter and a half-gallon accumulator. The latter supplies peak flow demands and maintains a constant valve inlet pressure.

The servo valves are connected directly to each of the two power cylinders to minimize the amount of oil under compression. The natural frequency of the cylinder and oil is much higher than the natural frequency of the loads. The cylinders are standard high pressure double acting units, reinforced by the addition of a threaded cap to hold the rod packing and prevent blowouts. The rods are chrome plated to reduce friction and increase packing life.

An I-beam is secured to the frame of the vehicle by braces, so that it extends beyond the sides of the vehicle. Power cylinders, which drive the system, are connected to the ends of the beam and to floor plates by ball joints. The ball joints prevent binding in the cylinders, which could be caused by the change in wheelbase and tread when the vehicle is stroked. Also, because of the change in tread, the wheels are located on a load platform that is free to move on roller bearings. This serves to isolate the load measuring cells from side forces.

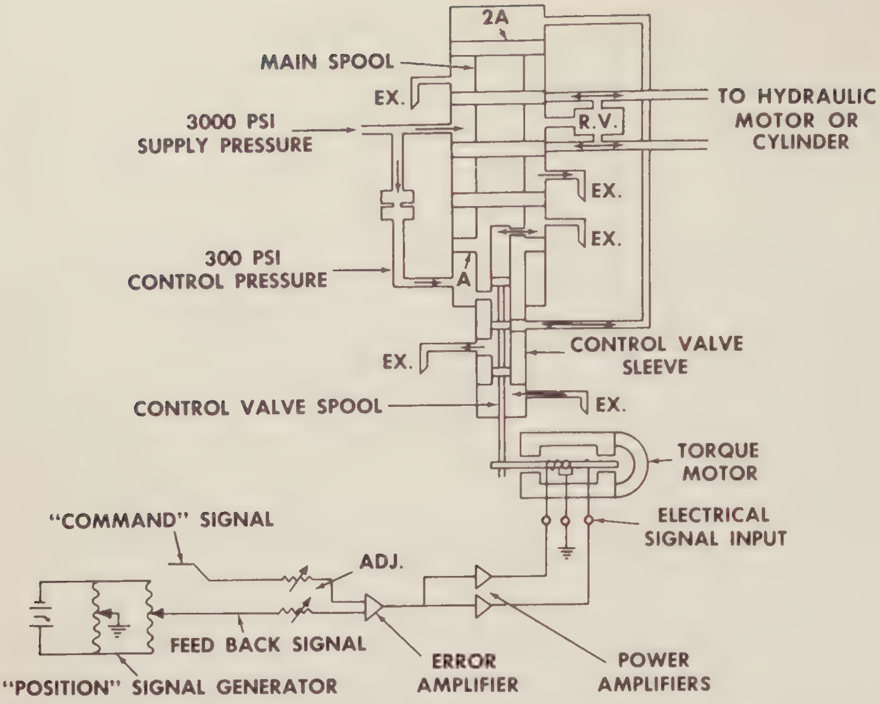


Fig. 3—A two-stage servo control valve is used in the simulator. When an electric current is passed through its coils, the torque motor of each valve moves a small lightweight control spool which uncovers the feed port to the upper end of the main spool.

The sense of the current (plus or minus) determines whether oil is to be fed to or exhausted from the upper end of the main spool. If the control valve spool is moved down, for example, the oil would flow to the top of the main spool, displacing it downward until the control valve sleeve, which contains the port, has again covered the feed port. This cuts off flow to the upper end.

As the main spool moves downward against a hydraulic spring (of zero rate) it always balances the control valve sleeve at the same point on the control valve spool. Therefore, since the main oil flow volume is proportional to the position of the main spool, it also is proportional to the electric current.

their hop frequency was readily at hand—chassis rolls. The chassis rolls, about six feet in diameter, are installed below the laboratory so that their tops are at floor level. As the wheels of the stationary vehicle roll over these cylinders, they pass over a series of spaced bumps, in the form of short plates bolted to the roll surface.

Drawbacks to the chassis rolls quickly became evident. The system strokes the wheels for only part of their full stroke, and then at only one stroking speed—the resonant frequency of wheel hop. The idea of using chassis rolls had to be discarded because of the difficulties in instrumentation and the lack of control over the stroke.

Vertical movement of vehicle wheels driven on the road usually takes the form of simple harmonic motion. It is an easy matter mathematically to work with a sine wave representing this motion. These facts made it highly desirable that any road simulator stroke the vehicle in simple harmonic motion. Some early attempts to create this motion were machines using air cylinders and poppet valves. These were used with limited success. Control of the stroke velocity and the end points of travel proved to be troublesome, requiring large amounts of tailoring to produce near sine wave motion.

Another early thought for a drive system was the reliable crank and adjustable speed motor. One trouble with this kind of mechanism was that it became too complicated when the stroke was made adjustable during operation. The size of the flywheel needed to maintain sine wave motion at low speed with heavy vehicle load would be enormous, although an amplidyne drive would reduce the size. Also, the ever present gear lash or belt stretch when going over center at the end of the stroke would be very troublesome.

Application of Hydraulics Provided an Adequate Drive

The application of hydraulics to drive power cylinders which stroked the test vehicle proved to be a solution to the problem of the drive system. It met all of the requirements of force and speed, and a suitable servo valve for control made sinusoidal stroking possible beyond the frequency of the vehicle body motion.

The hydraulic system which was chosen for the test apparatus consisted of (a) two power cylinders to stroke the vehicle and (b) the necessary control equipment (Figs. 1 and 2).

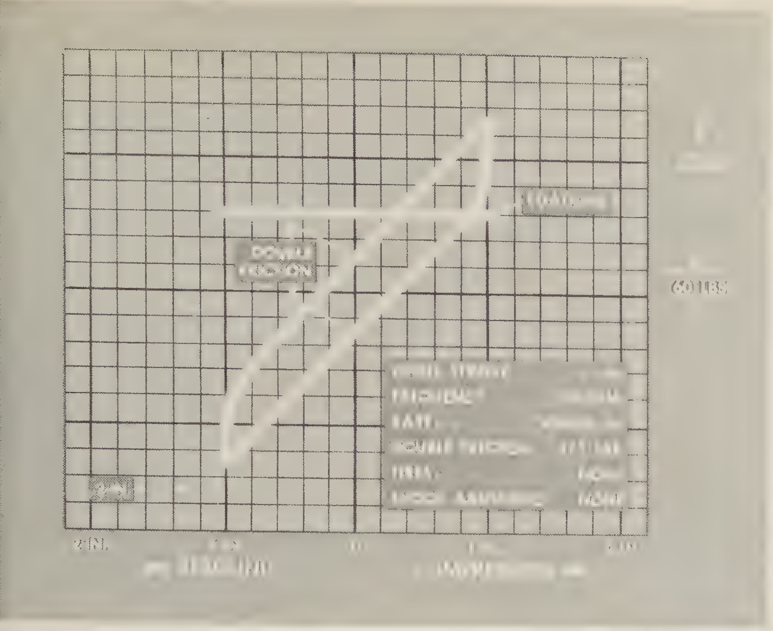
An I-beam was secured to the frame of the vehicle by braces, so that the beam extended beyond the sides of the vehicle. A power cylinder was connected to each end of the beam with a ball joint. The other end of each cylinder was secured to a floor plate through a similar ball joint. The ball joints were needed to prevent binding in the cylinders, because the wheelbase and tread changed slightly as the vehicle was stroked. The change in wheelbase also necessitated locating the wheels on a load platform that was free to move on roller bearings. The roller bearings isolated the load measuring cells from side forces.

Servo Valves Control the System

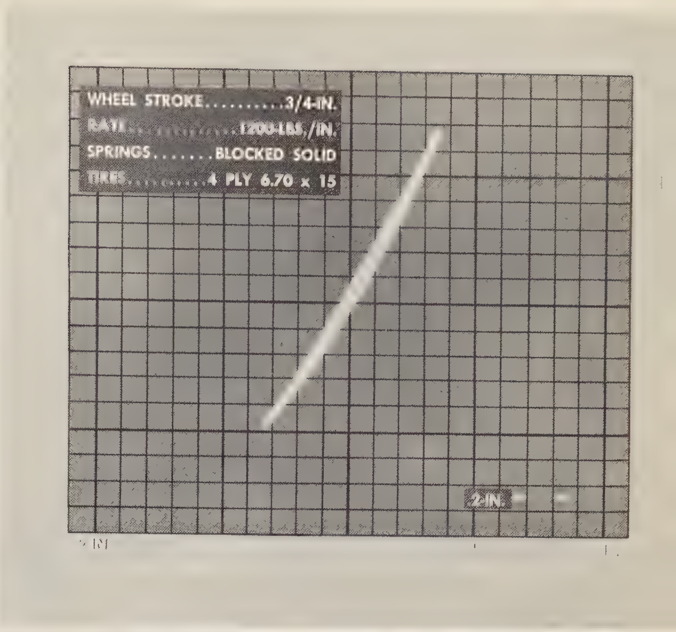
Control over the hydraulic cylinders was provided by an electro-hydraulic servo valve system (Fig. 3). Electric signals passed through an amplifier and actuated a torque motor which, in turn, operated a valve system that controlled the flow of oil to and from the cylinders.

Since the flow rate (gpm) of the forcing oil was proportional to the input electrical signal, the piston of the power cylinder had a velocity which was proportional to the signal. For test operation the piston position should be proportional to the signal. Therefore, a null-type control was worked out as follows. The command signal was mixed with a feedback signal which was proportional to the position of the vehicle. These two signals were mixed in such a manner that, as the command signal opened the valve and moved the vehicle, the displacement increased the feedback voltage to buck or cancel the command signal, restoring the mixing amplifier voltage to zero. When the voltages were equal there was no output from the servo valve and the vehicle remained in position at a displacement proportional to the command signal.

The output voltage from the mixing amplifier was fed to the input of two power amplifiers. Each coil of the torque motor was powered by a separate power amplifier.



a


WHEEL STROKE..........3/4-IN.
RATE..............1200-LBS./IN.
SPRINGS.......BLOCKED SOLID
TIRES..........4 PLY 6.70 x 15

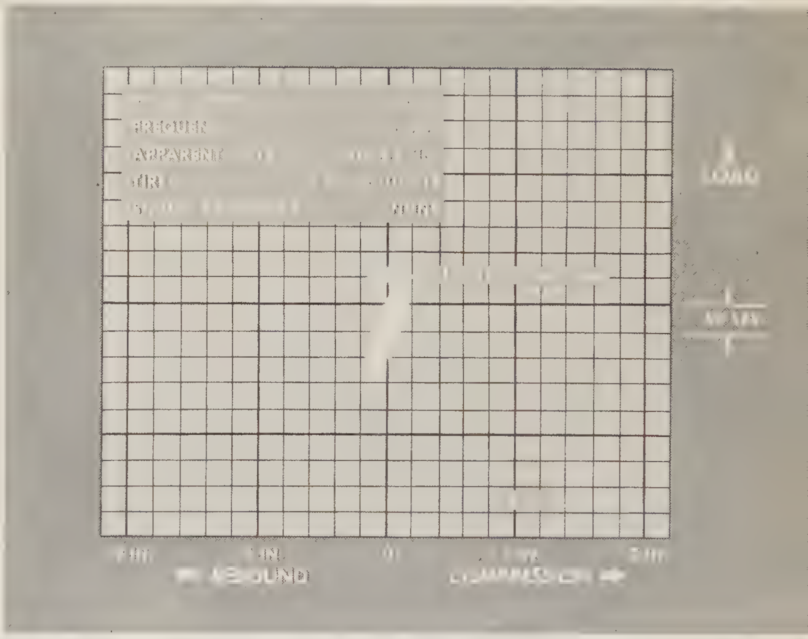
b

Fig. 4—The plots shown here are photographs of the oscilloscope which were taken by a self-developing camera during suspension tests. Plot (a) reveals the behavior of a front suspension like that on most half-ton trucks—with a solid axle and leaf springs. The tires and shock absorbers had been removed. The springs were in the "as installed" condition after operation for 10,000 miles. There was no grease or anti-friction material between the leaves. The plot shows clearly that the spring rate was linear at 300 lb per in. The load line gave a positive check of amplifiers and scope drift. It will be noted that there was double friction in the system of approximately 175 lb. Double friction is the difference between load in compression and load in release, and is caused by interleaf friction and friction at pivot points, such as bushings. The difference between these loads and the elastic force of the spring is known as the friction force.

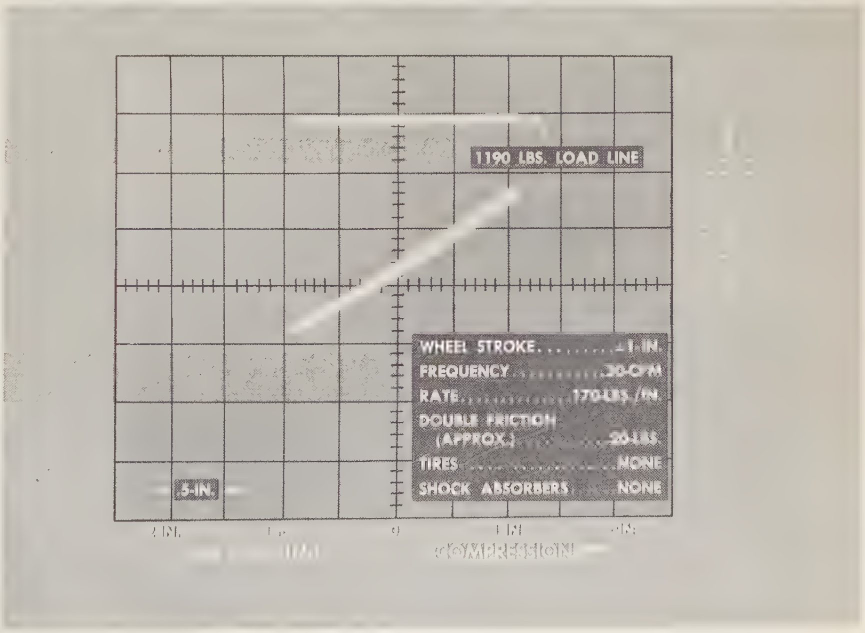
Plot (b) is a reproduction of the tire rate of a typical truck tire—a four ply, 6.70 tire inflated to 24 psi. The spring rate here was 1,200 lb per in., an extremely high rate.

Plot (c) shows the results of a test performed with the same set up as that shown in plot (a) and with the same tires as shown in plot (b). The significance of this curve is that the effective spring rate of the vehicle, when riding on semi-smooth pavement, was almost equal to the rate of the tires alone due to the friction.

Plot (d) is the rate curve of an experimental low friction suspension. The rate of the spring was 170 lb per in. But the most significant feature was the very low friction in this suspension—approximately 20 lb of double friction. The highway feel of this vehicle confirmed the results of the machine. There was complete absence of sharpness or harshness in the ride. The low spring rate of the suspension contributed greatly to the smoothness and low friction reduced the harshness in the ride.



c


WHEEL STROKE..........±1-IN.
FREQUENCY..........30-CPM
RATE..........170-LBS./IN.
DOUBLE FRICTION (APPROX.)..........20-LBS.
TIRES..........NONE
SHOCK ABSORBERS..........NONE

d

For automatic control, a commercial laboratory signal generator was used to produce the sine wave command signals. For manual control, 3-turn helical potentiometers were geared to a hand-controlled knob so that one-fourth turn gave full deflection. Maximum deflection for each wheel was set on a separate dial, permitting the operation of the two sides at different length strokes. This operation could simulate a situation where one side of the vehicle is on a smooth surface and the other on rough, such as might occur on a narrow country road. Trim height (height under load at rest) of a truck or car could be changed by altering the bias voltage on the signal generator. This method permitted the simulation of a heavy load without stopping the test and changing the actual load. The mode of stroking could be changed from parallel hop to tramp by a reversing switch, which inverted the command and feedback signals to one valve.

For obtaining roll rates, the cylinder force had to be applied at a position corresponding to the center of gravity of the vehicle. At the same time the feedback signal had to be taken from the vehicle at the height of the roll axis, where it crossed the transverse plane passing through the center of gravity.

Total Measuring System Contained Several Components

In the measuring system for detecting reactions of the test vehicle, both the vehicle loads and the wheel deflections had to be obtained by electrical means to prevent the danger of phase lag at high speeds. For indicating displacement, a simple 3-turn potentiometer resistor and battery was selected. One end of a strong line was tied to the sheet metal of the car under investigation, the other end being wrapped around a drum on a potentiometer incorporating a spring return mechanism. The potentiometer rested on the ground.

Strain gage load cells were used to measure the force that the wheel and tire exerted upon the ground. The cells were the notched cantilever kind, using strain gages to read the beam deflection. Proving ring cells using a linear variable differential transformer (LVDT) were considered, for they have a much larger electrical output than strain gages. Their use could have eliminated some of the difficulties encountered in amplifying low level strain gage signals. However, the large physical size of the proving rings and the ease of fabricating the cantilever beams made the strain gage units more favorable in this case.

Each load platform carried four cantilever load cells, each of which contained a complete strain gage bridge. To obtain the total load, the output of the four cells was added in series. The power source for each bridge was a 12-volt storage battery with an adjustable resistor for voltage control. Before assembly, each cell unit was calibrated on a tensile test machine to give the same output voltage per pound of load.

To calibrate the load cells after they were installed, the individual voltage for each cell was set approximately by meter. Final adjustment was made by shorting a calibrated resistor across one leg of each bridge. The output, in millivolts, was read on the oscilloscope. Zero load was obtained by raising the wheels of the vehicle off the load platforms. It was found that the scope amplifier was adequate to provide a readable, 120 lb of load per in. of deflection on the oscilloscope.

Complete shielding of all wires and components connected with the load circuit was needed to prevent pickup from the 60-cycle power lines and lights. To insure against drifting by the d-c amplifier of the oscilloscope, a load line from a standard cell, representing a known load, was scribed on the load deflection curves immediately after or before a test run. The deflection signal for the curve was operated the same way that the feedback voltage was obtained—by a strong line connected to a helical potentiometer resistor, commonly called a helipot.

Direct Read-Out Sought

After the measurement of load and wheel deflection had been made, it was necessary to record the data in a simple and easy-to-read manner. The ideal result would have been a direct plot of the wheel load versus the wheel deflection. The standard *x-y* recorder appeared to be suitable; however, existing commercial units would not provide large curves at the 100 cycles per minute frequency. Even if one of the recorders had been hand tailored to give the desired results, the recorder would have limited future test expansion into higher cycling rates. On the other hand, it was possible to get excellent results by tape recording all data at high tape speed, then playing back on a standard *x-y* recorder at one-tenth speed.

As a temporary measure, an oscilloscope and self-developing camera were used as a read-out device. To obtain a true plot from the oscilloscope, the grid had to be calibrated for maximum and minimum values of load and deflection. The scope was linear within two per cent (Fig. 4).

The recorded plot was a photograph of the oscilloscope screen, made with a self-developing camera bolted directly to the base of the scope. Using this camera, a print was obtained in about one minute. A light hood to shield the oscilloscope face from stray light, a slip-on lens for close-up work, and a cable release were the only accessories used.

In making readings from photographic prints, a number of cautions had to be observed in the interests of accuracy. The lens system of the camera was not designed for extremely close work, and it produced distortion. Thus, scaling with a straight edge on the finished print, or using slope as rate lines, produced inaccuracies in readings. By using the grid on the oscilloscope screen and reading from line to line on the photograph, accurate results were obtained. The line to line reading also made unnecessary the use of glass photographic plates such as those used in close photogrammetric work.

Summary

Although proof of the suspension is still in the actual ride on the road, a simulator unit can eliminate much of the cut-and-try from developmental work. Simulators enable a design engineer to check his work and make adjustments on the new suspension design in the laboratory. The simulators provide quick and accurate observation of the suspension under operating conditions, without requiring lengthy and inconvenient road tests. A simulator greatly reduces the time span between conception of a suspension design and its final production form.

The drive versatility and accurate measurement ability of the new Chevrolet simulator make it a valuable addition to suspension testing facilities. Chevrolet engineers believe that refinement of operating technique and good correlation between simulator readings and ride observations will enable this machine to make a significant contribution to the development of future suspensions.

Studies of Radioisotopes Show Promise for Present and Future Applications in Engineering

By FARNO L. GREEN
General Motors
Research Staff

The possibilities of using the atomic nucleus for the benefit of mankind have stimulated the work of scientists and engineers ever since radioisotopes were first made artificially with accelerators, such as cyclotrons and Van de Graaff accelerators, in the early 1930's. However, useful quantities of radioisotopes were not generally available until the end of World War II from the Oak Ridge National Laboratory Graphite Reactor (first known as the Clinton Pile). Since that time, with increased availability of radioisotopes, great potential has become evident in industry as well as in other areas such as medicine and agriculture. Utilizing the benefits of radioisotopes in industry, however, has presented the vexing problems of cost and the scarcity of reliable data. There is also a scarcity of engineers who are trained in radioisotope uses. The pattern has been one of much study and modest progress. The General Motors Research Staff is engaged in the long-range work of collecting new basic nuclear data, learning more about nuclear techniques, and learning how to apply them successfully in developmental and production situations. It is expected that the present limited use of radioisotopes will, in time, be expanded and that radioisotopes will become a most important engineering and production tool.

Using radioisotopes, like making soy sauce, requires the right ingredients and lots of time

In a few years radioisotopes will be frequently used in industry so that some nuclear techniques will be as familiar to engineers as an ion exchange column is to the chemical engineer, the oscilloscope to the electrical engineer, the strain gage to the mechanical engineer, and the transit to the civil engineer.

The honorary chairman of the General Motors Board of Directors, Alfred P. Sloan, Jr., can recall how, as a young engineer with Hyatt Bearings Division, he toured auto manufacturing plants to sell engineers on the idea of using roller bearings. Today every engineer knows where a roller bearing is applied and what handbooks he should use for design data.

Someday engineers will have a handbook for radioisotope utilization and nuclear techniques, thanks in good measure to the Atomic Energy Commission's initial job of selling industry on the idea of using isotopes.

Meanwhile, it must be admitted that at present industry is only beginning to collect its apparatus and skills. For both research and production, modern technology requires new skills, particularly in utilization of the atom.

Up until this time the most significant strides in the use of radioisotopes have been made in medicine. Nuclear triumphs in the industrial field are necessarily slow because techniques are still crude. Supplies of a variety of isotopes are not abundant. Nuclear data are so new that much are unreliable. If an engineer or physicist wishes to try something different for a new application, he frequently takes only two steps before he stumbles. Then he must call time out either to do basic research or he must drop his program. As yet relatively few things can be done well with available materials and well-known techniques, for the state of the art is somewhat primitive.

Utilization of radioisotopes in industry is comparable to the status of the United States in 1849. The cry of "Gold!" had been heard around the world. Many people thought that the United States was a great country because gold nuggets were lying exposed on the ground in California and that any passer-by could cure all his life's hardships by picking up a few nuggets.

The cry "Radioisotopes!" has already been heard in industry because a few nuggets of potentially wide utilization, such as thickness gaging, have been found. Real industrial progress will not be great with radioisotopes just because

Fig. 1—The opening of the General Motors Isotope Laboratory in 1956 was a major step in pioneering the uses of radioisotopes. In this building are facilities for numerous types of research and developmental projects, such as nuclear data collection, chemical tracer experiments, electronic developments, radiography, and wear studies.

of a few nuggets. Progress will be great after continued exploration to discover the true extent and quality of our different natural resources which are radioisotopes themselves and the physical principles by which they can be used. Also, now and for many years to come, much hard labor is required to clear the new ground, plow the fields, sow the seeds, and reap the harvest. Decades, not just months and years, are required to realize the full potential of the land of industrial application of radioisotopes.

For progressive use of radioisotopes, people in industry and the general public have yet to be emancipated completely from slavery to the idea that invisible "death-rays" from radioisotopes are evil and cannot be used with as much safety, in numerous applications, as the table lamp in the living room. General education will continue to allow greater freedom to make engineering progress and applications.

Worth keeping in mind is the fact that the same historical pattern once prevailed in various branches of science outside the nuclear field.

This brings to mind the fact that the X-ray, spectroscopy, special electronic gadgets, and other quality control techniques didn't appear overnight in modern industry. First they had to prove themselves in the laboratory. Then they moved into the production cycle, but not without some doubt and skepticism as to their reliability and usefulness.

Admittedly, possibilities for new nuclear techniques in production are vast. But phasing them into the production and processing area take time and study, basic research, and experimentation. The possibilities have to be proved to plant managers.

In any mass production industry the plant manager has day-to-day schedules to maintain. If he produces a certain part or small assembly and his mechanized assembly line is operating well enough to meet these schedules, his understandable wish is to leave the line alone. He feels no pioneering compulsion to introduce some newfangled technique. After all, in the beginning it was difficult enough to get his overall production cycle debugged.

Paradoxically, assembly techniques and heavy production schedules, anywhere from 20,000 to 100,000 units a day, do present some problems. An axiom of any high production operation is: "After you detect a flaw in an assembly, you may have a barn full of bad parts before you can walk over and punch the 'stop' button."

So, if something goes wrong and the plant manager winds up with a barn full of useless parts or assemblies, he may excusably yield to anxiety. He needs help—any kind of help. At this point the engineer or scientist who can solve the problem must be ready on the double to put a new device on the assembly line, a device that assures the manager his production will flow again—flawlessly.

Applying Radioisotopes Like Preparing Soy Sauce

The dilemma of this plant manager is something like the do-it-yourself chef who once telephoned a library. He needed a recipe for soy sauce because he had forgotten to pick up a bottle at the grocery on his way home. His dinner was almost cooked. He held the phone while the librarian found a recipe and read it to him. This is what the recipe said:

> *Light Soy Sauce* (*Yuen You*)
>
> 10 cups soy beans
> ½ cup salt
> 6 gallons water
>
> "Mix all ingredients and cook together until boiling. Lower heat, simmer 5 hours (about 5 gallons of water should be left). Strain, Pour into 5-gallon glass jar. Seal airtight. Keep the jar where it can face the sun for about one year or more. Needs plenty of sunshine. This liquid is light soy sauce."

At the other end of the telephone line there was a pause, followed by a weak "thank you." The do-it-yourself chef hung up.

Successful use of radioisotopes for some of the most promising industrial projects is like soy sauce preparation. The right ingredients and lots of time are needed. "Plenty of sunshine" in the development atmosphere is essential. All of these cannot be compressed instantaneously into a sauce while the plant manager's dinner simmers.

What is General Motors doing about isotopes and nuclear techniques, specifically with an eye toward improving quality control and production?

In 1953 a decision was made to construct an isotope laboratory at the General Motors Technical Center (Fig. 1). The complete facilities of this laboratory (Fig. 2), operated by the Research Staff, were put into operation in 1956. The program of the Isotope Laboratory is aimed at:

(a) Applying existing nuclear techniques to research, developmental and production problems (Fig. 3)[1, 2]

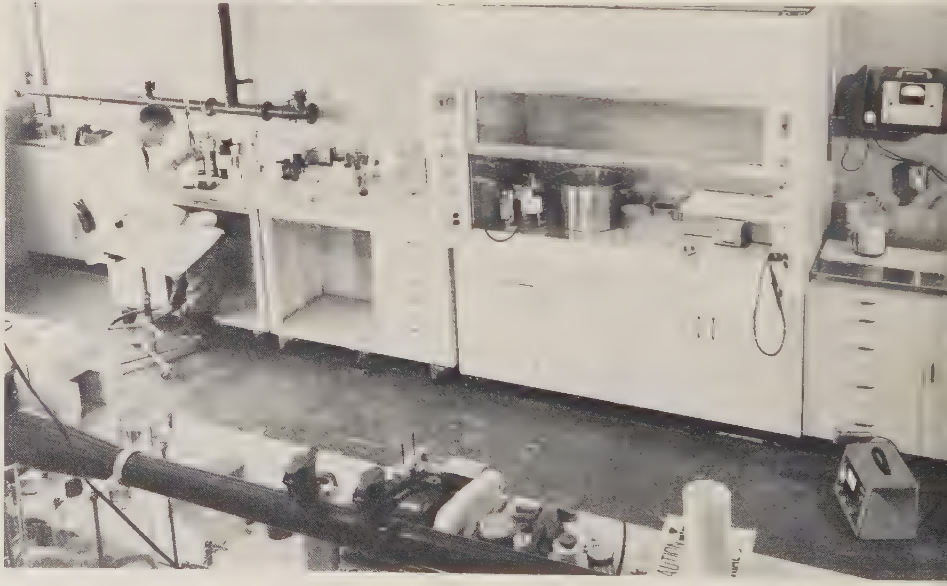


Fig. 2—Typical laboratory space in the Isotope Laboratory is flexible to allow various experiments and developments. This particular area is a low radioactivity level laboratory in which chemical experiments are performed. A laboratory monitor, using a Geiger Muller tube which is mounted on the wall to the right of the hood, is used to check hands and glassware for freedom from contamination. A similar instrument is on the floor. At the lower left is an iron brick cave used for shielding radioactive samples. Bottles on top are non-radioactive. A special filter enclosed in the box over the hood removes any contaminated particulate matter from the air leaving the hood. Air is exhausted through the cylindrical fan housings shown on top of the Isotope Laboratory in Fig. 1.

(b) Developing new radioisotopes and improved nuclear techniques which can be applied to General Motors problems (Fig. 4)[3]

(c) Performing fundamental research with long-range GM motivation

(d) Educating GM personnel in uses of radioisotopes and nuclear techniques.[4]

As examples of current radioisotope uses, there are more than 20 density-thickness gages[5] in use in three GM plants and there are several radiography installations which use Cobalt-60. Most of these were initiated by the GM Divisions assisted by various commercial suppliers.

What about precision inspection? In some cases only one part out of 1,000 is faulty in a finished product at the end of a production line. This may seem phenomenally good, but it is far from good enough in the automotive business.

In some cases radioisotopes with short half-lives look to be well suited for inspection processes because they rapidly lose their radioactivity. The only trouble is that materials with short half-lives usually are not available. What is needed, in some cases, is a gamma-ray emitter with a short half-life. For example, it could be painted on a part moving down the assembly line and used as a "present-not-present" indicator in the final assembly at the end of the line.

The half-life would have to be so short that the customer would get none of the radioactivity. Just as important is the fact that the radioactivity would have to vanish soon enough to obviate the storage problem. Ten microcuries of iron-59 is a very small quantity of radioactive iron. But 200,000 small parts each containing 10 microcuries, warehoused in a space the size of a coat closet, would produce total radioactivity of two curies of iron-59—enough to produce serious handling problems. For storage reasons alone, the radioactivity ought to decay within a few hours after inspection.

Some new radioisotopes with short half-lives in 10 to 100-curie quantities a day are needed. They must be produced at locations not subject to shipping delays by weather conditions, if they are to be used in the production processes.

Research Staff Studies Techniques and Applications

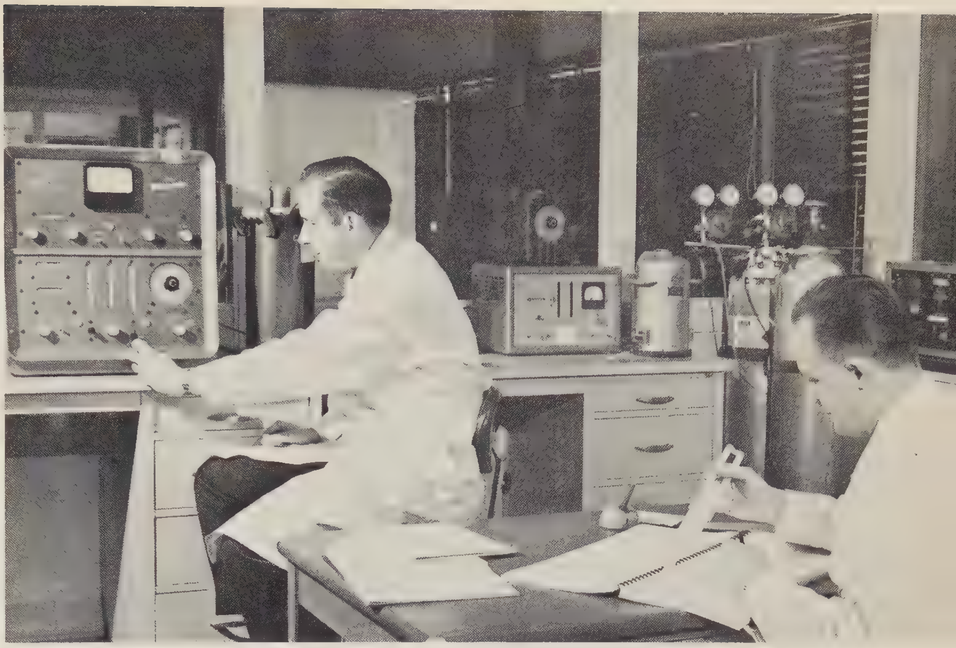


Fig. 3—A chemist on the left is using a well-type NaI crystal housed in a cylindrical lead shield for checking the intensity of a radioactive standard. Standards are necessary for numerous projects, such as fundamental nuclear research, refrigerator wear, piston ring wear, and chemical tracer studies. A mathematician is making a statistical analysis of numerical data which were collected with the gas-flow type proportional counter shown on the table in the center.

One of GM Research Staff's long-range problems is to translate laboratory-type instrumentation into something that will be rugged and reliable for use in a production plant. Unfortunately, in applying nuclear techniques, the physical principle may be ingenious, and the mechanical design inventive, but if the instrumentation does not function reliably every minute of the production shift the whole technique is useless.

As an example, a plant manager might request assistance from the Research Staff Isotope Laboratory on a particular problem. Engineers of the Laboratory might recommend a device which they think will solve the plant manager's problem. Such a device is a scintillation crystal detector to measure radioactivity, a gamma-ray detector with a 1¾ in. by 2 in. sodium iodide scintillation crystal and preamplifier. The detector is rushed from the Laboratory to a spot on the assembly line where it should function unattended.

When the detector is moved into its new environment where it is needed to measure radioactivity, the engineer's trouble begins to mount. In the location where the detector must function, the temperature over an 18-hour period may vary from 55 to 105 degrees. The floor may vibrate as if a fast freight was passing 15 feet away. Humidity may vary 50 per cent. Rapid fluctuation in line voltage may occur due to operation of welding machines. In some cases the detector may even be installed within an exhaust duct, where it is subjected to dust or a corrosive atmosphere.

At any rate, those are some of the problems—not exactly insurmountable but certainly considerable. Indeed, anyone who has used such a detector with associated instrumentation in an air-conditioned, atmospherically controlled laboratory knows well what problems an engineer faces. In a competitive production situation, a plant manager might have his next model run completed before successful operation of a newly developed nuclear technique could be achieved.

What about the ways in which the use of radioisotopes may affect other fields of engineering?

Mechanical Engineering

When boiled down to the number of man hours spent, a good many jobs using radioisotopes such as die wear measurements, or using a radioisotope as a tag on an assembly line, are about 90 per cent mechanical engineering. Shielding or remote handling may complicate mechanical problems. In another case, in order to apply the atom to a specific gravity measurement of a corrosive, high temperature liquid, the engineer finds a knowledge of radiation and the nucleus

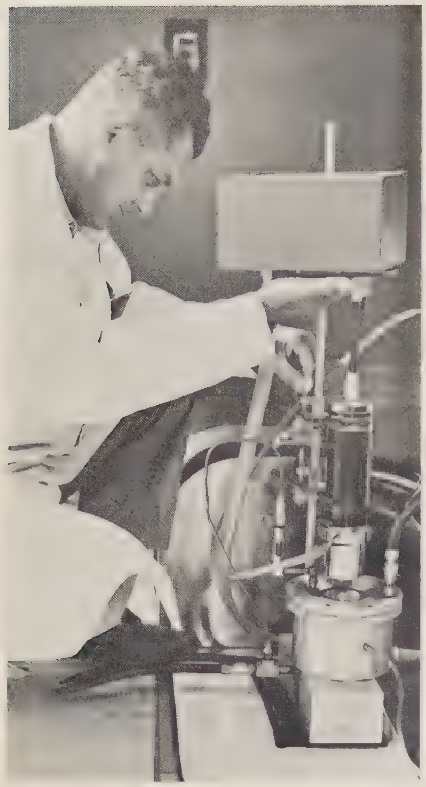


Fig. 4—A sodium iodide (thallium activated) crystal detector and photomultiplier tube are being lowered into a well-shaped sample holder which contains radioactive motor oil at elevated temperatures. The NaI crystal which detects gamma rays is enclosed in a water-cooled stainless steel jacket. The cooling jacket protects the physical state of the NaI crystal and reduces instabilities which would be introduced into the electronic counting system by any liquid in the holder which undergoes rapid temperature changes. No shielding around the radioactive sample holder is required for protection of personnel. The total amount of radioactivity in the holder is small. The well-shape sample holder gives improved counting efficiency. Using a NaI crystal for counting *hot liquids* with these advantages is a General Motors Research Staff development.

to be as useful as knowledge of pressure, temperature, and chemical effects.

Metallurgical Engineering

Radioisotopes are a good tool to use in locating the basic problems in several types of wear. The isotope allows definition of the problem; then the engineer is ready to use his older metallurgical skills.

Electrical Engineering (Electronics)

Some production processes would now be using radioisotopes if counting equipment were both reliable and of low cost. Certain types of counting equipment are designed only for laboratory use. An increase in the supply of electronics engineers familiar with milli-microsecond pulses would be an asset both to instrument manufacturers and to users of radioisotopes. Additional development is needed to produce commercial electronic counting equipment which is better for plant uses from the standpoint of reliability, size, and cost.

Electrical Engineering (Power and Radio Frequency)

The use of charged particle accelerators is the only way with present day technology to produce half of the known radioisotopes and to observe excited-state nuclear characteristics of many isotopes. Applications in this field are very minor thus far because much work needs to be done to lower the costs of accelerators and to improve their reliability.

Engineers working in the areas just discussed need not be nuclear engineers. They could be today's practicing engineers who have been given a sound conventional engineering education and the additional benefit of a few selected courses in nuclear technology and applications.

Nuclear Engineering and Nuclear Science

The more fundamental work belongs here. Basic nuclear information which is potentially useful to engineers lies dormant in volumes of *The Physical Review* because there are few engineers or applied physicists available to ferret out and utilize the information. Some specific examples are: (a) half-life and radiation characteristics of radioisotopes that have never been used in industry, and (b) isotopic excited-state data which have been collected with accelerators such as Van de Graaff machines and cyclotrons. A machine such as a Van de Graaff accelerator promises to become one of the most sensitive analytical tools known for obtaining certain specific engineering data.

More Nuclear Education Needed

New engineering education is needed. Nuclear engineers and nuclear scientists should be groups who contribute significantly to the total sum of basic knowledge. The supply of conventional engineers with some nuclear knowledge is limited; consequently, the burden of work which they could be doing falls on the shoulders of nuclear scientists and engineers who might be doing basic work.

Eventually, the normal education system will produce a larger supply of "engineers with nuclear knowledge," as distinguished from nuclear reactor engineers, a specialist group unto themselves. An engineer with nuclear knowledge probably should not have more than 10 per cent of his nuclear education devoted to reactors—important as they are—because a nuclear reactor is only one of the many atomic devices that may be useful to the engineer in industry.

Because engineers with nuclear knowledge are almost unobtainable, and because engineering schools will not generally be producing these men for several years, the General Motors Research Staff is cooperating with General Motors Institute in operating a 10-week intensive training course. Men from various operating divisions of GM are enrolled. Equivalent training in an engineering curriculum would be about 11 semester hours of lecture and six semester hours of laboratory. The GM course is open only to selected GM employes with bachelor degrees, or the equivalent in engineering, physics, or chemistry. Already three classes of six students each have graduated and two more classes are on the way.

At the research level, meanwhile, work is going ahead on some basic pioneering jobs with radioactive atoms. This behind-the-scenes work in nuclear technology will, in time, help General Motors to produce products of higher quality and improved reliability at lower cost.

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An Application of Radioisotope Wear Study Techniques

By CHARLES C. GAMBILL
Frigidaire
Division

Applying a new technique
with the ultimate objective:
improve the product

In the past, few if any satisfactory methods have been available for measuring extremely small amounts of wear in a short time, continuously, and under normal operating conditions for any particular mechanism. In the search for a better method, the Frigidaire Division has conducted a test for finding otherwise undetectable amounts of wear in a refrigeration system compressor through the use of radioactive wear study techniques. This test, conducted at the GM Research Staff Isotope Laboratory, was found to be very successful and was used to evaluate the ability of three oils to prevent wear.

WHEN evaluating a refrigeration system oil, one of the properties which is investigated is the lubricity of the oil. One of the facets of lubricity, the ability of the oil to prevent wear, may be evaluated by determining the amount of wear that the oil permits. In the past this determination has been difficult when the amount of wear has been small, that is, measurable in micrograms. Recently, a test was conducted in which the lubricities of three oils were compared through the use of radioactive wear study techniques. Although the test was used to evaluate the lubricity of the oils, it was specifically designed to determine the advantages and disadvantages of employing radioactive wear study techniques to make this evaluation.

The test was a conventional radioactive wear test which was conducted on refrigeration system rotary compressors, that is, a wearing part of the compressor was made radioactive. As the part wore, its wear particles were collected, detected, and their weight determined by methods to be discussed as follows.

How a Radioisotope Was Chosen

A small part of a compressor, the vane, was chosen to be made radioactive. Since the vanes are approximately 98 per cent iron, it was known that Fe^{59} could be produced by neutron bombardment of

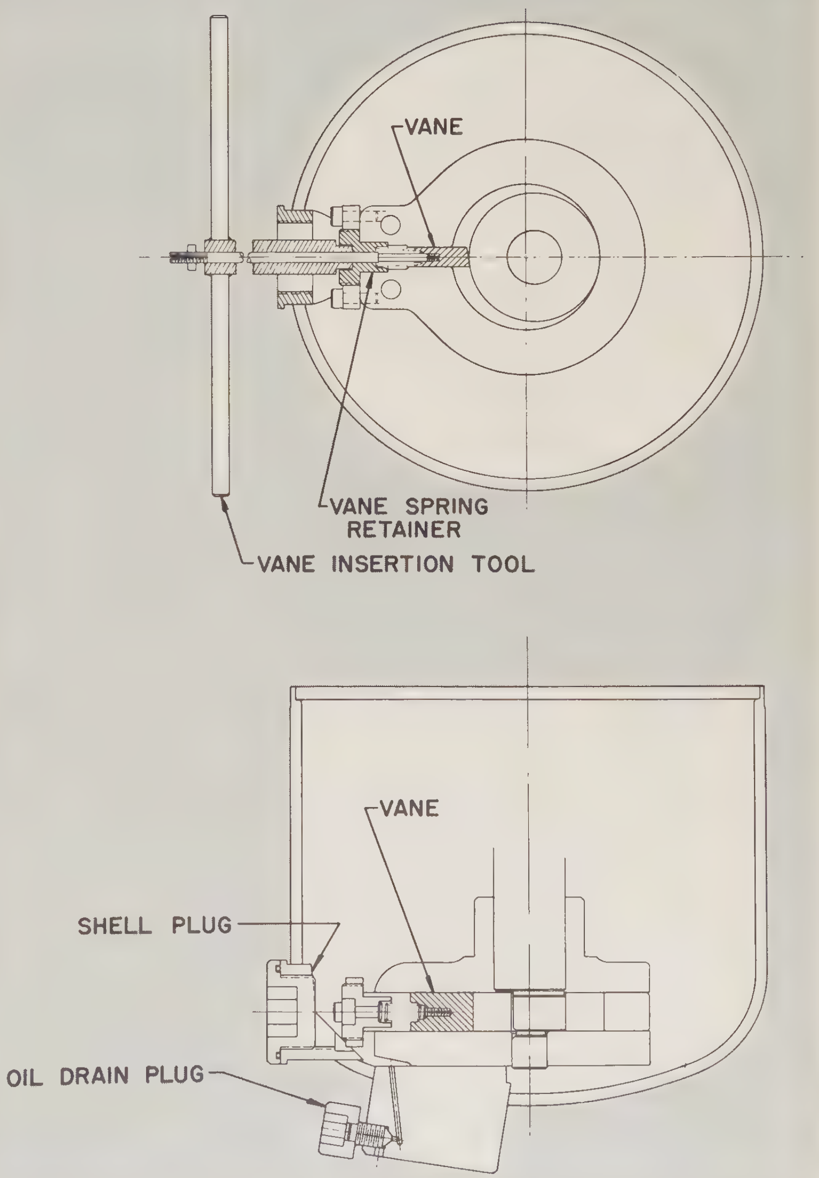

Fig. 1—To conduct the wear study of vanes in a refrigeration compressor, special modifications to the compressor were made to permit quick insertion of the vane into the compressor and to facilitate oil sampling. At the right are shown the arrangement of the oil sampling valve and the special vane insertion port. After a test vane was irradiated, it was inserted quickly into the port.

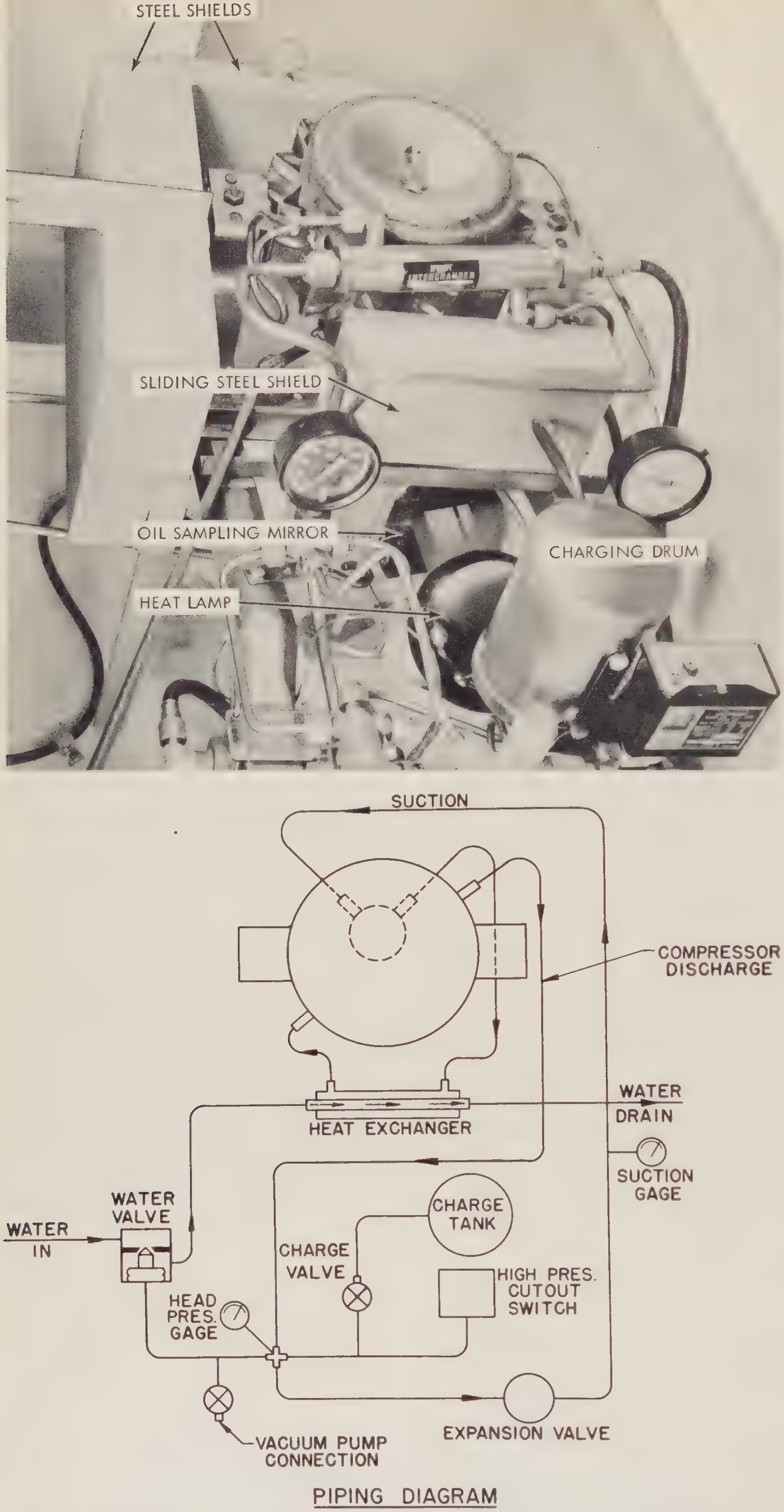

Fig. 2—The modified compressor was installed in a specially protected test stand (top). Shown at the bottom is a piping diagram of the simulated refrigeration system. The pressure-operated water valve kept the head pressure at 250 psi by regulating the amount of water flowing through the heat exchanger. The back pressure was maintained automatically at 20 psi by an expansion valve. The heat lamp heated the charging tank and helped to force the enclosed oil and refrigerant into the system. The steel shielding was used for protecting the operator from gamma radiation. The sliding steel shield permitted the vane to be inserted and could then be moved to protect the operator when taking oil samples.

Fe^{58}, which is present in natural iron along with the other stable iron isotopes Fe^{54}, Fe^{56}, and Fe^{57}. Iron-59 atoms are unstable and disintegrate giving off, among other radiations, a gamma having an energy of 1.1 Mev and another gamma having an energy of 1.3 Mev. These gammas may be easily detected in several ways.

Iron-59 has a half-life of 45 days, that is, if 2×10^8 atoms of Fe^{59} disintegrate per second at time zero, 1×10^8 atoms will be disintegrating per second after 45 days and 0.5×10^8 atoms will be disintegrating per second after 90 days and so on. This half-life was very convenient because the compressor vanes could be used for several months, since one-fourth of the original vane radioactivity was still present after 90 days. On the other hand, the vane radioactivity continued to decrease after the completion of the test so as to facilitate proper safe disposal.

Wear Particles Collected in Oil Samples

Two 1/7 hp rotary refrigeration compressor units were used for each of the three oils to permit a check of the reproducibility of results for each oil. As the oil lubricated the compressor vane, it also removed the wear particles from the vane. It was assumed, therefore, that the wear particles would become suspended in the oil. Oil samples were taken through a sampling valve at predetermined intervals during the test for the purpose of monitoring the wear rate (Fig. 1).

Simulated Refrigeration System Set Up in Glove Box

The modified compressor units were placed on a special test stand and connected so that they could operate against normal head and back pressure for high load conditions (Fig. 2). The refrigerant, cycled by the compressor, was cooled by a water-cooled heat exchanger to simulate actual service conditions. A tank was attached to each refrigeration system and was charged with oil and Freon-12. The charge in this tank was not used until the irradiated vanes were inserted. With heat applied to the tank, it was possible to quickly charge the system without requiring an operator to remain in the radiation field of the irradiated vane.

Prior to the installation of the irradiated vanes, the refrigeration systems were checked for satisfactory operation while using a normal charge of oil and Freon-12

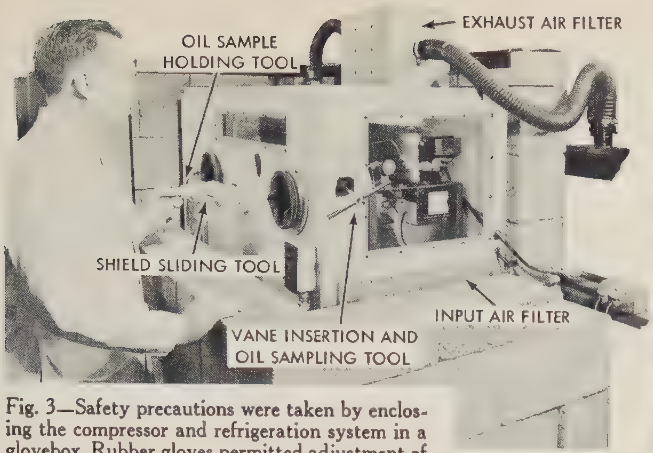

Fig. 3—Safety precautions were taken by enclosing the compressor and refrigeration system in a glovebox. Rubber gloves permitted adjustment of the test components. Polyethylene bags were taped to the vane insertion and oil sampling tools to prevent the possibility of spreading wear particles outside the box as the tools were partially removed. Waist-high concrete shielding was complemented with steel shielding (Fig. 2).

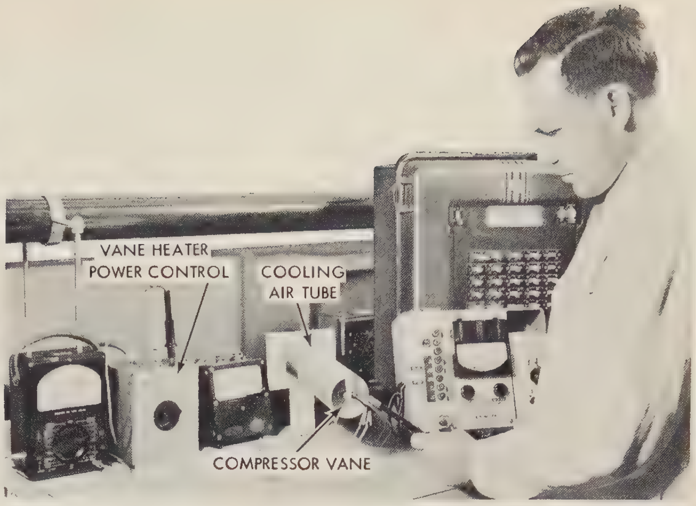

Fig. 4—It was reported that the reactor hole would produce gamma heating of 0.5 watt per gram of vane. In the above test setup, the same heating was applied to the vane, and cooling air velocity and temperature were simulated. From this study, an irradiation container was designed which sufficiently dissipated the heat.

and employing a standard unirradiated vane. It was found that at least four ounces of oil could be removed without affecting the operation of the system. It was decided, therefore, that oil samples could be taken and need not be replaced as long as not more than a total of four ounces of oil was removed from the system.

A glove box was used to enclose the compressor units and the remainder of the refrigeration system. These boxes were made nearly airtight for safety purposes in the event of an oil sampling accident or a Freon-12 leak. In either event, radioactive wear particles might be discharged into the atmosphere where they could be inhaled if they were not contained by the box. If wear particles had been discharged in the glove box, they would have been removed by a vacuum system and caught in an exhaust air filter. If a large Freon-12 leak caused a positive pressure in the glove box, an input air filter was designed to serve also as an exhaust filter and to catch the wear particles.

Rubber gloves were installed in the box to permit adjustments on the refrigeration system. Ports of slit rubber were installed for easy operation of vane insertion, oil sampling, and shield sliding tools. Polyethylene bags taped to the tools and glove box prevented the possibility of the tools spreading wear particles outside the glove box when they were partially removed. A pass box, with double doors, was used for introducing or removing tools or oil samples without opening the glove box directly to the test room atmosphere.

Concrete and steel shielding were used to protect the test operator from the gamma radiations emitted by the compressor vane (Fig. 3). This shielding and the test in general were designed with a safety factor which would permit using 100 millicuries of radioactivity per vane. Actually, 20 millicurie vanes were used since it was felt that this amount of radioactivity would allow adequate test sensitivity.

Vane Irradiation Required Special Preparations and Containers

To insure the uniformity of radioactivity in the compressor vanes, all vanes were made from the same batch of bar stock and therefore had the same metallurgy. The vanes were standard with the exception that they had a tapped hole for use in inserting them in the compressor with the tool designed for that purpose. All vanes were carburized and hardened at the same time to insure uniformity in these operations.

A decision was made to have the vanes irradiated in an air-cooled reactor hole. This hole was reported to produce gamma heating of 0.5 watt per gram of vane. It was necessary, therefore, to design a vane irradiation container to dissipate this heat sufficiently to prevent annealing of the hardened vane.

A test set up was constructed to simulate the gamma heating problem (Fig. 4). A heater inside a compressor vane supplied 0.5 watt per gram of vane. The vane cooling air velocity and temperature were the same as that of the reactor hole. The vane temperature was checked by the use of thermocouples while it was en-

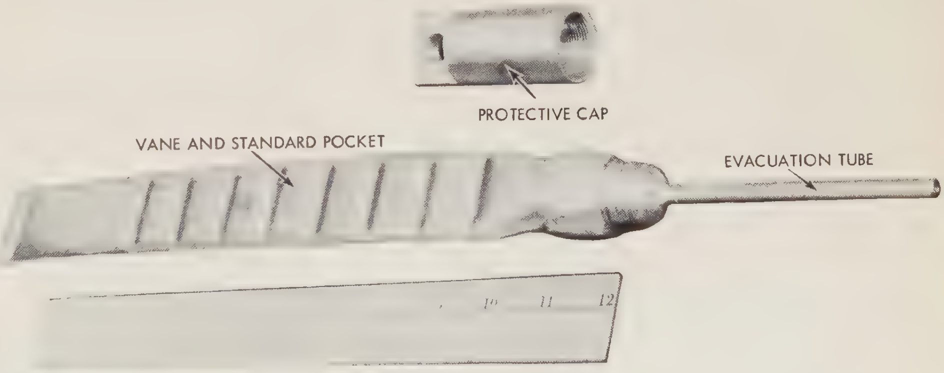

Fig. 5—A special design was made for an aluminum container to hold the compressor vanes while they received irradiation in a reactor. Eight separate pockets were provided in the container. A vane and a small piece of metal from another vane of the same metallurgy (used as a standard) were placed in each pocket. Air was removed from the container and it was filled with helium to increase heat dissipation and thus prevent a change in hardness of the vanes. The evacuation tube was sealed and cut. The protective cap was used to protect the sealed evacuation tube and to facilitate handling of the container at the reactor.

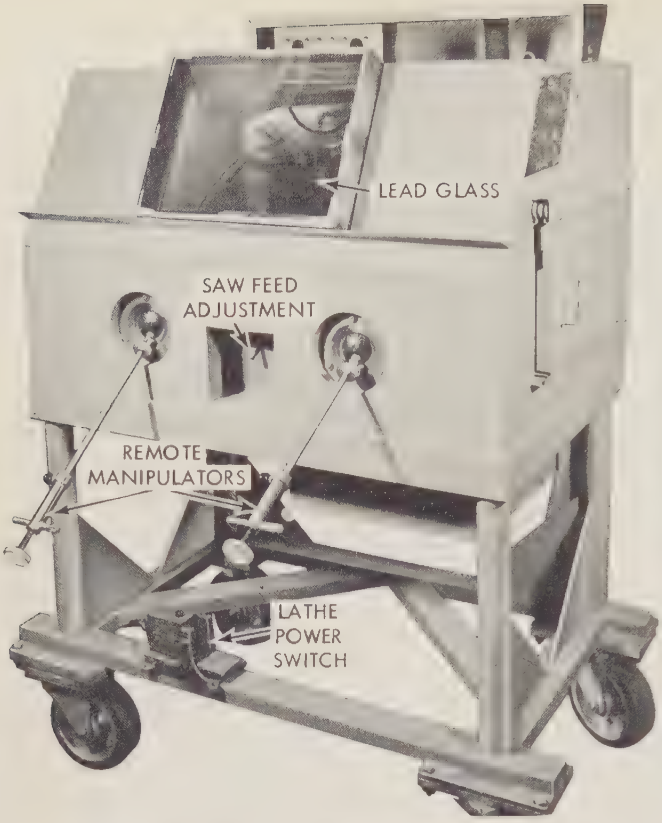

Fig. 6—The irradiated vanes were removed from the container by means of a circular saw blade in a lathe. This operation was performed in a lead and lead glass shield, as shown above. The blades also were cleaned and inspected here before installing them in the test compressor.

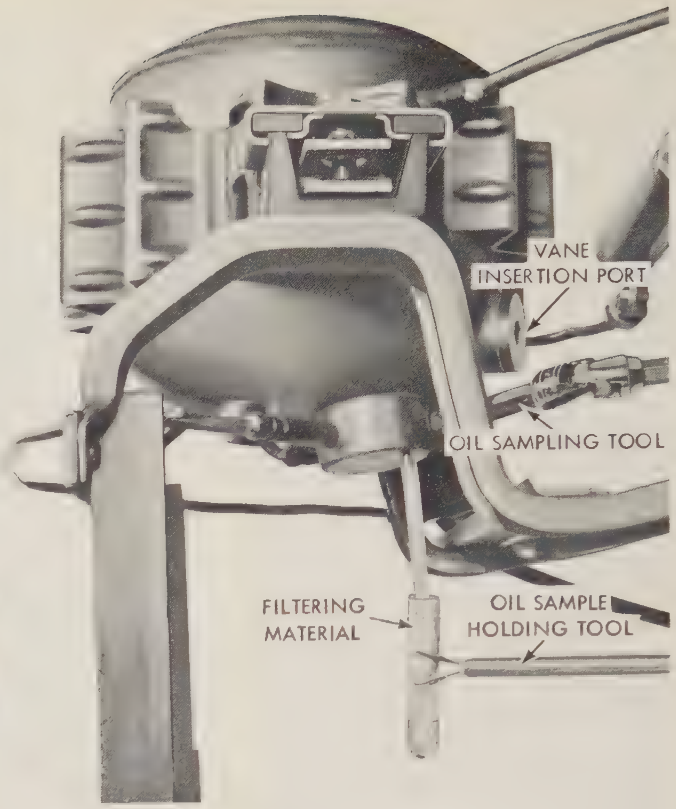

Fig. 7—During the operating test of the compressor, oil samples were withdrawn through the oil sampling valve. The oil passed through a short piece of flexible tubing into a plastic test tube. In the rotary compressors used in this test, the oil and Freon-12 were not separated. Therefore, as oil samples were taken, Freon-12 also was released. The filter at the top of the test tube allowed the release of the Freon-12 but caught the oil and wear particles which could escape with it.

closed in several designs of 2S aluminum irradiation containers. A container was devised which dissipated heat at a rate which prevented the vane temperature from exceeding 200° F. It was found that the vane hardness was not changed when heated to this temperature.

A vane and a small piece of material from another vane having the same metallurgy were placed in each of eight pockets of the irradiation container (Fig. 5). The pieces of vane were included for use as vane standards. Although only six compressor units were used, eight vanes were placed in the container in the event that some would become damaged before they could be inserted in the compressors. The air was removed from the container and it was filled with helium to prevent rusting of the vanes and to increase heat dissipation from them. (Helium was selected for filling the irradiation container, among other reasons, because it was chemically inert, a good conductor of heat, and because it would not be made radioactive as a result of irradiation.)

After the vanes were irradiated and returned from the reactor, they were removed from the irradiation container by cutting the container with a circular saw blade in a lathe. The lathe was enclosed in a glove box behind a lead and lead glass shield (Fig. 6). The glove box was connected through a filter to a vacuum system to remove any helium-borne or air-borne radioactive particles.

The vanes were cleaned with acetone, sodium hydroxide, water, and chloroform. Sodium hydroxide was used to remove aluminum container chips. The vanes were then placed in a container holding oil of the type in which they were to be used.

Visual inspection of the vanes was made through the lead glass of the shield. They also were observed under a microscope behind lead shielding.

A hardness test was made on the irradiated vanes. They were found to have a hardness of 79 Rockwell N. An unirradiated vane was also found to have a hardness of 79 Rockwell N.

The vane standards, which were irradiated alongside the complete vanes, were dissolved and found to have approximately equal specific activities. This indicated that the neutron flux was nearly constant over the length of the irradiation container. The total activity per vane was found to be approximately 20 millicuries.

Oil Samples Taken and Wear Particles "Counted"

After the vanes were inserted in the compressor units, the refrigeration system was evacuated. The system was then charged with oil and Freon-12 from the charging tank. All compressor units were started and run continuously throughout the test.

At predetermined intervals during the test, oil samples were withdrawn from each compressor through an oil sampling valve and collected in plastic test tubes (Fig. 7).

The equipment used to detect the radioactive wear particles in the oil sample consisted of a scintillation crystal, a photomultiplier tube, amplifiers, and a mechanical register (Fig. 8). The radioactive wear particles constituted a source which gave off gamma rays that struck the scintillation crystal. Part of the gamma rays caused light scintillations which produced electric pulses in the

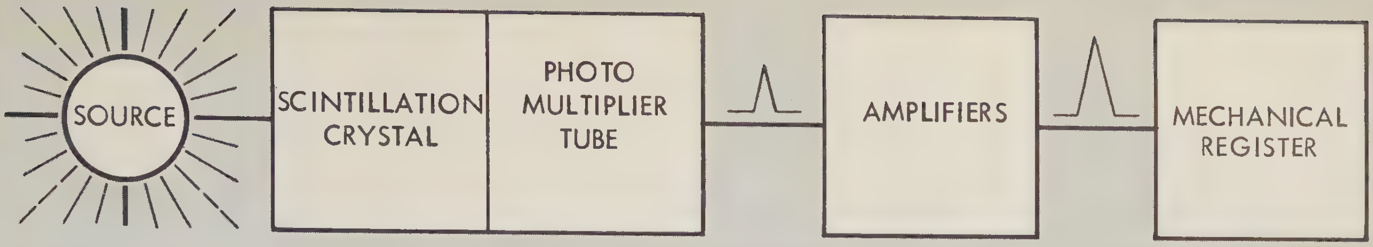

Fig. 8—This block diagram illustrates the equipment used to detect the wear particles found in the oil sample during the test. The radioactive wear particles are shown as a source which gives off gamma rays that strike a scintillation crystal. Part of the gamma rays cause light scintillations which produce electric pulses in an attached photoelectric tube. These pulses were electronically amplified and applied to a mechanical register where they were indicated as "activity" counts.

attached photoelectric tube. These pulses were electronically amplified and applied to the mechanical register where they were indicated as "activity" counts.

A dissolved vane standard of a known weight was counted every time the wear particles in an oil sample were counted. Since the vane standard was irradiated alongside the vane whose wear particles were being detected and since they had the same metallurgy, the number of counts from each was directly proportional to the weight of vane in each. The weight of the wear particles in the oil sample, therefore, could be computed since the weight of the vane standard was known. The weight of the wear particles in the oil remaining in the compressor was determined since the weight of this oil was known and the weight of the oil sample was measured.

At every sampling time, two oil samples were taken from each compressor unit to determine if the wear particles were uniformly distributed in the compressor oil. These samples were always found to contain approximately the same amount of wear particles. At the end of the test, the oil was drained from each compressor. Oil samples, taken from the oil drained from each compressor, were found to contain the same amount of wear particles as were found in the oil samples taken from the same compressor just prior to the end of the test. It was shown, therefore, that the particles were evenly distributed in the compressor oil and that the oil samples were accurately representative of the total compressor oil at any time.

Lodged Radioactive Wear Particles

After the oil was drained and the vanes were removed, it was found that some radioactive wear particles had remained lodged in various parts of the refrigeration systems as would certainly be expected. The weight of those particles was found as follows:

(a) Each part was counted for radioactivity

(b) The part was flushed with an organic solvent and counted again. The percentage of radioactive wear particles removed was then computed

(c) The flush was counted and compared to the count of a standard of a known weight of vane. The weight of radioactive wear particles in the flush was then calculated

(d) Since the weight of radioactive wear particles in the flush was known and since the percentage of radioactivity removed from the part by the flush was known, the weight of the vane wear particles in the part, before the flush, was calculated.

Total Vane Wear

The total vane wear was found by adding the weight of the wear particles in the drained compressor oil, in the oil samples, and those which lodged in various parts of the refrigeration systems. It was found that the vane wear in the oil samples was indicative of the total vane wear in each compressor. On the basis of total vane wear, two of the three oils had lubricities which made them acceptable for use. The third oil was shown to be definitely inferior.

Technique Has Sensitivity; Can be Further Simplified

In this test it was found that by using vanes with 20 millicuries of radioactivity, radioactive wear study techniques could be used to find easily even a fraction of a microgram of wear. This was accomplished in a few weeks while operating the refrigeration system under normal conditions. It was also found that oil lubricity could be accurately evaluated.

Since completion of this test, radioactivity measuring equipment of greater sensitivity has become available. Tests on oil samples indicate that this later equipment is at least five times as sensitive as the equipment used in this test. In future tests, therefore, the vane radioactivity could be reduced from 20 millicuries to 4 millicuries without affecting the accuracy of the test results.

If the vane radioactivity had been only 4 millicuries in this test, no external shielding would have been necessary because the compressor units contained enough steel to provide sufficient shielding. With the absence of external shielding, simplifications would have been possible in glove box design, vane handling tools, oil sampling tools, and in all procedures conducted in the glove boxes. The time required for the irradiation of the vanes and their return to the laboratory would have been reduced as would the irradiation costs. With the lower amount of radioactivity, all radiological safety problems would have been simplified. It may be seen, therefore, that the test cost and time could be significantly reduced in any future wear tests by the use of new and more sensitive radioactivity measuring equipment.

Conclusion

The results of this test were very gratifying since the evaluation of the lubricities of the three oils was made quickly, easily, and accurately. As increasingly better radioactivity measuring equipment becomes available, it is felt that radioactive wear study techniques will become an even more powerful tool.

Acknowledgment

The author acknowledges the guidance of Dr. A. Somerville, GM Research Staff, GM Technical Center, and the help of the Isotope Laboratory personnel in connection with the work reported in this paper.

The Design and Development of a Synchronous Firing Device for Twin 40mm Guns

A recent problem encountered by engineers of Cadillac Motor Car Division's Cleveland Ordnance Plant concerned rotation of the gun mount used on the M42A1 mobile carriage. Recoil forces, resulting from the firing of twin 40mm guns, acted on the gun mount in such a manner as to cause rotation in alternate directions. The problem was to design a synchronizing device which would synchronize firing of the guns and, in turn, cause the recoil forces to act simultaneously to reduce gun mount rotation. Before a design program could proceed, however, it was first necessary to study data obtained from previous firing tests and also the firing cycle of the 40mm gun. This study resulted in establishing a point at which synchronization should start. The next step was the design of the synchronizing device within rigid design specifications. Test firing of the 40mm guns with the synchronizing device proved that all design expectations had been realized.

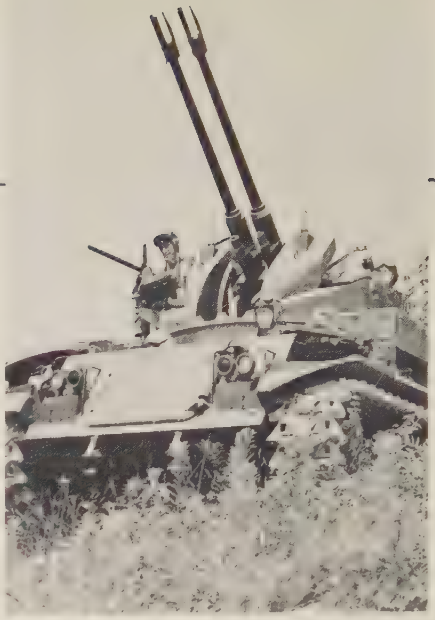

Fig. 1—The M42A1 self-propelled track-laying mobile carriage has twin recoil-operated 40mm guns mounted on trunnions. The vehicle carries a crew of six—commander, driver, gunner, sight setter, and two loaders—and is used primarily as a defensive weapon against low flying aircraft. It also can be used effectively against ground targets. The guns fire fixed percussion-type ammunition which is loaded into automatic loaders in clips of four rounds each. Tendency of the gun mount to rotate due to recoil forces acting on the gun trunnions required Cadillac Ordnance Plant engineers to develop a device to synchronize firing of the guns. The synchronizing device allowed the recoil forces to act simultaneously on the trunnions. This eliminated the tendency for gun mount rotation and, in turn, resulted in minimum target error.

The M42A1 self-propelled mobile carriage built by the Cleveland Ordnance Plant of Cadillac Motor Car Division is an armored, full-track laying vehicle mounting twin, recoil-operated 40mm guns (Fig. 1). The guns fire either single fire or automatic fire at the rate of 120 rounds per minute per gun. After the guns are triggered for automatic fire, each gun operates independently of the other. Because of a variation in firing rate between the two guns the complete range from simultaneous firing to alternate firing may be covered. This may occur, for example, during a burst of 16 rounds.

The twin guns are mounted on trunnions positioned 24 in. apart. The trunnions, part of the gun mount, are mounted on a 36-in. diameter ring gear. A reversible gear train mechanism is used which may be either hand or power operated.

Recoil Forces Created Problem of Gun Mount Rotation

Recently, Cadillac Ordnance Plant engineers were concerned with a problem of gun mount rotation due to recoil forces acting on the trunnions. As the guns left the simultaneous firing condition and approached the alternate firing condition, the recoil forces acting on the trunnions tended to rotate the gun mount in alternate directions about the vertical

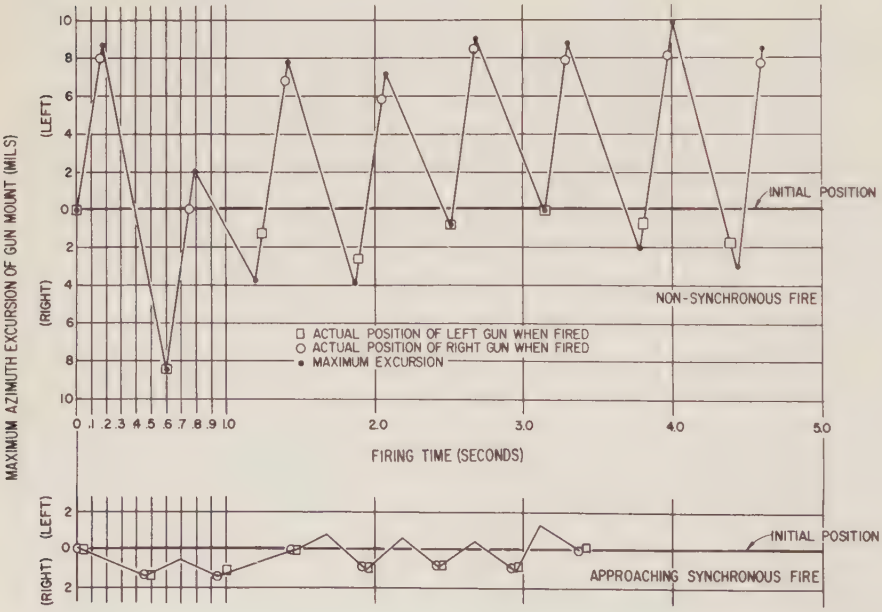

Fig. 2—Shown at the left is the result of one phase of a preliminary firing test conducted to determine the amount of gun mount azimuth excursion when the twin 40mm guns were fired under conditions of single fire, automatic fire, varying degrees of synchronization, and various firing rates. This particular chart is for an automatic, non-synchronous firing sequence with manual gun mount control and shows the change in azimuth position of the gun mount relative to its initial position at the time of firing. The maximum azimuth excursion as plotted is correct with respect to excursion distance only, not necessarily with respect to time. The firing tests indicated that azimuth excursion of the gun mount was reduced from about 18 mils during non-synchronous firing to less than 2 mils for synchronous firing.

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Simultaneous action of recoil forces reduces gun mount rotation

axis of the ring gear. This led to a greater dispersion of the rounds than was desired. It was felt that if the guns were synchronized the recoil forces would then act simultaneously on each trunnion. This would reduce the tendency of the gun mount to rotate.

A design and development program was inaugurated which had as its goal a synchronizing device which would meet the following requirements:

- Low initial cost
- Low cost for field modification
- Operation in the event of power failure
- Allowance for either gun to continue firing if the other gun malfunctioned
- Rugged and simple design with minimum weight.

In addition, the synchronizing device had to be an integral part of the twin gun arrangement and could not cause a change in other major components. Also, the device could not detract from the overall simplicity of daily or periodic maintenance or decrease the firing rate.

Preliminary Firing Tests Established Desired Degree of Synchronization

In 1953 the U.S. Army conducted a test which consisted of firing twin 40mm guns at radio-controlled aerial targets. These targets flew crossing passes at a range of approximately 1,000 yards and an altitude of 1,000 ft. Cameras, secured to the gun mount, recorded gun mount azimuth movement relative to the target. Motion pictures also were taken to record gun mount movement relative to the hull and to the earth. The data obtained indicated that a study of gun mount movement, using accurate instrumentation, was in order to determine the degree of synchronization necessary to reduce target error.

A firing test was then scheduled using the following instrumentation:

- An electric timing and firing device to control the cyclic rate of each gun and, in turn, the degree of synchronization desired. This was done by firing each gun single fire at any desired rate up to 120 rounds per minute per gun
- A camera attached to the gun and with its lens fixed on a grid mounted on the ground at a known distance from the gun
- Displacement pickups and potentiometers to record azimuth movement of the gun relative to the hull and time, vertical movement of the guns relative to the gun mount and time, and the firing cycle of each gun from start of recoil to return to battery (firing position). The displacement pickups were connected to carrier and linear-type amplifiers which, in turn, were connected to a calibrated oscillograph.

Some 1,400 rounds were fired during this test under conditions of single fire, automatic fire, varying degrees of synchronization, and various firing rates. The test simulated firing at fixed targets only. This eliminated variables that

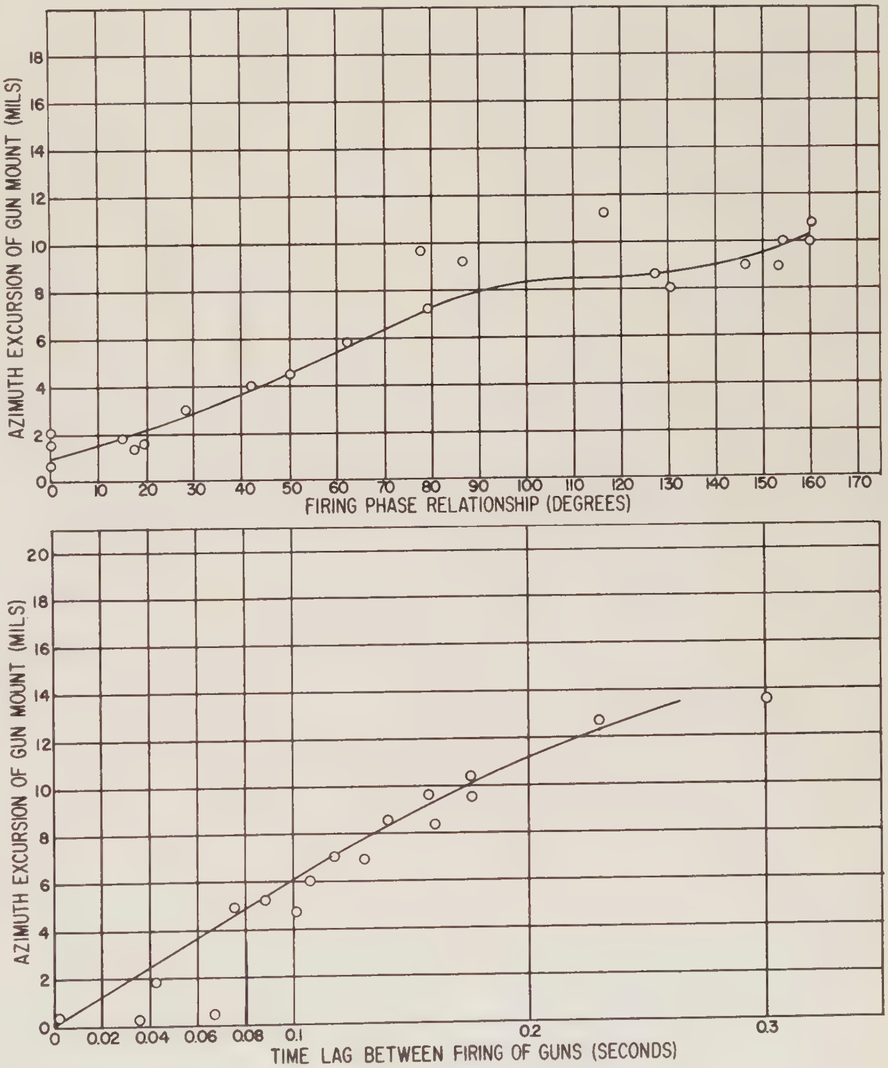


Fig. 3—Firing tests conducted by the U.S. Army in 1953 showed that gun mount azimuth excursion was reduced as the guns neared the synchronous firing condition (top). Another important factor was the effect the time lag between firing of the guns had on the total azimuth excursion and, in turn, dispersion of the rounds (bottom). Azimuth excursion decreased when the time lag decreased. It was felt that if the guns could be synchronized within 0.06 seconds a major reduction in dispersion would result.

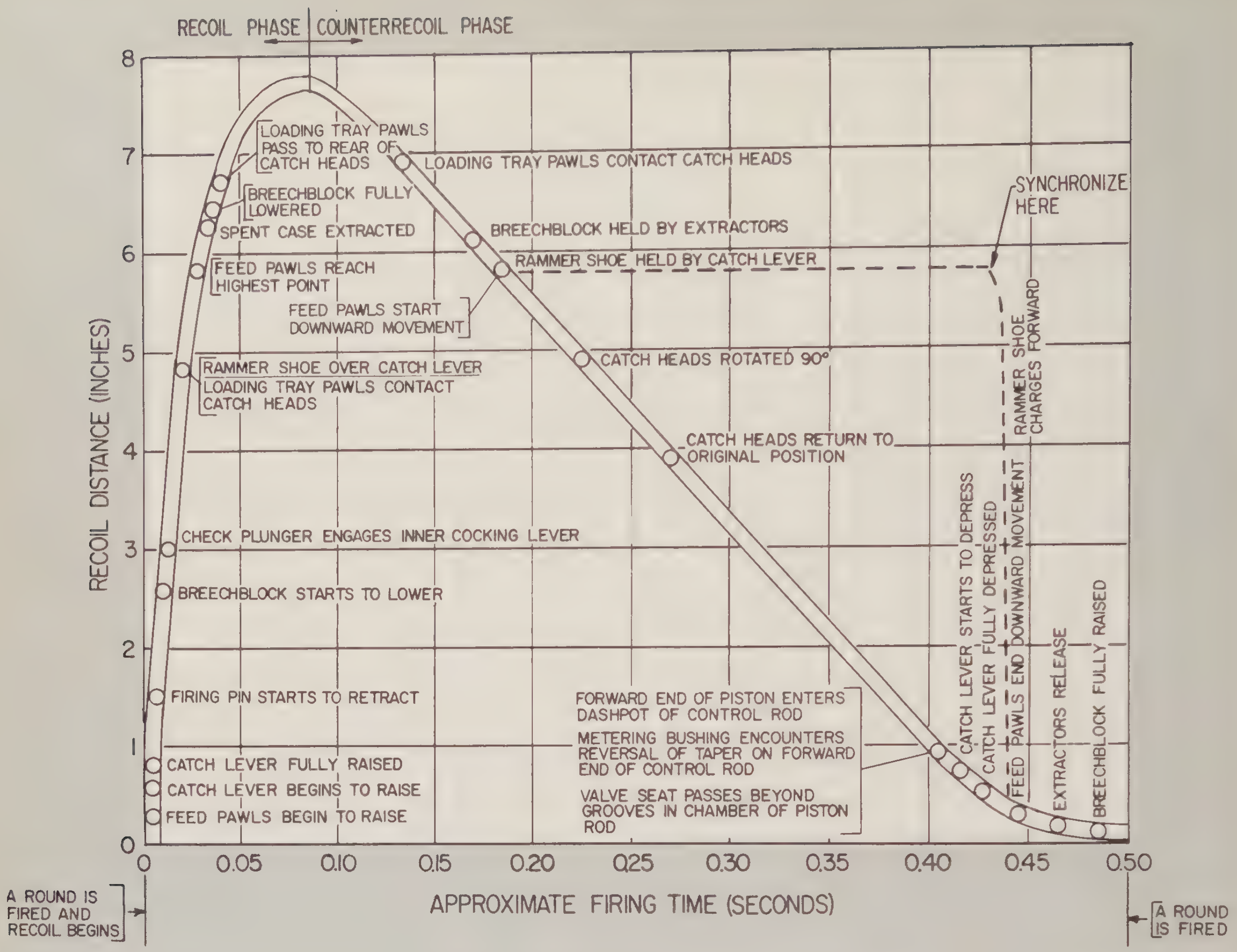


Fig. 4—The first step in the design of a device for synchronizing the firing of the twin 40mm guns was to make a thorough study of the firing cycle from the time that recoil began until a round was fired. The study indicated that synchronization should start at 0.07 seconds before the round was fired. This is at the point where the rammer shoe is released, or charges forward, during the firing cycle.

would occur through tracking of targets, such as human error, sight error, and mechanical error in the gear train.

The firing test provided pertinent data. Azimuth excursion of the gun mount was reduced from about 18 mils in non-synchronous fire to less than 2 mils for synchronous fire (Fig. 2). Also, azimuth excursion was reduced almost proportionately to the degree of synchronization achieved (Fig. 3 top). For synchronous firing of the guns, vertical oscillation was reduced from about 4 mils to less than 2 mils. This was due to the long (0.5 seconds) and constant time interval between successive pairs of rounds, which gave the vertical oscillation of both the gun and gun mount time to decay. The test showed that if the guns could be synchronized within 0.06 seconds a major reduction in dispersion would result (Fig. 3 bottom).

Firing Cycle Studied to Determine Where Synchronization Should Start

The first step in the design of the synchronizing device was to study the firing cycle of the 40mm gun from the time recoil started until a round was fired (Fig. 4).

The ideal place to synchronize was at the firing pins when the first round was fired. This could not be done, however, without a major re-design of the breech mechanism. As one of the design requirements stipulated that no change of major components could take place, another approach to the problem was required.

It was next thought that if the rammer shoes were synchronized, the rounds could be rammed into the breeches simultaneously. This would leave only 10 per cent of the firing cycle time unsynchronized. This 10 per cent would consist of the rounds being rammed into the breech, the extractors released, breech blocks raised, and the firing pins released (Fig. 5). The time variation between the two guns for this portion of the firing cycle would be negligible.

It was decided, therefore, that synchro-

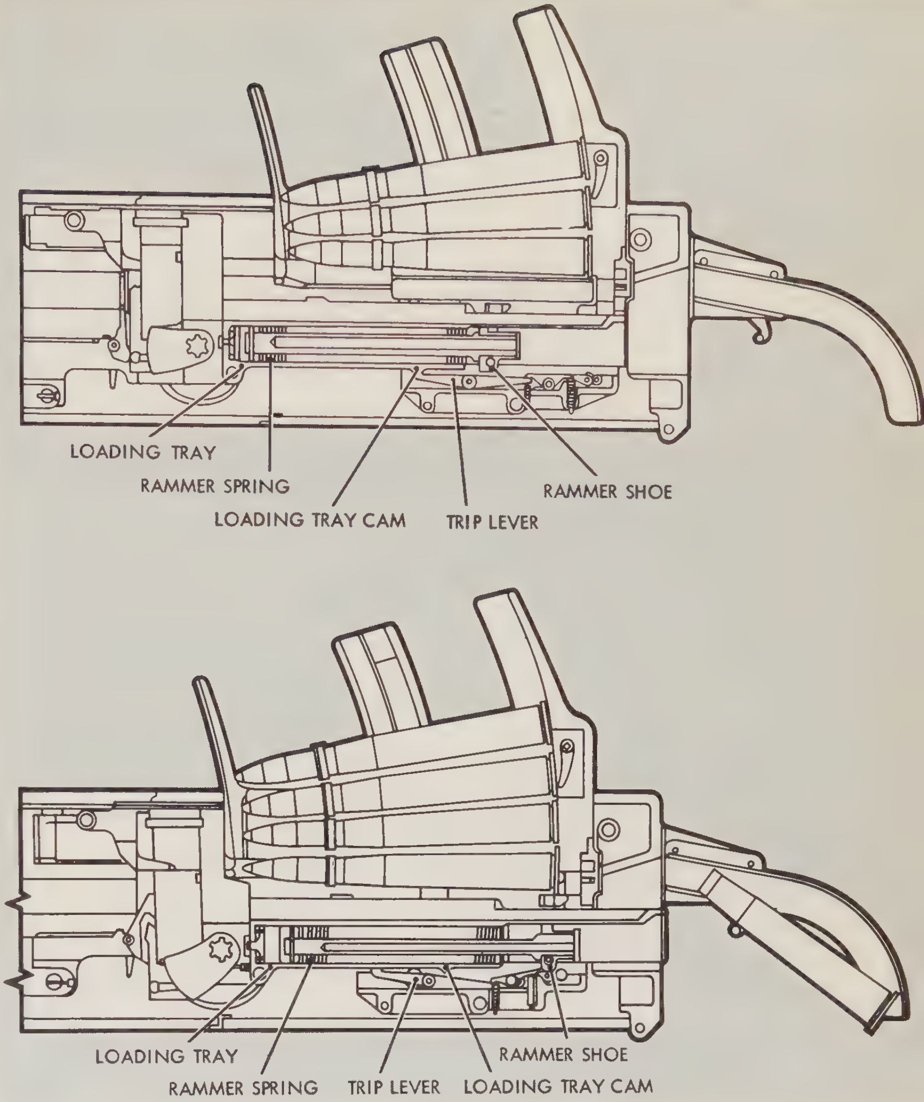


Fig. 5—A preliminary step in the design of the synchronizing device for the twin 40mm guns was a study of the firing action of a non-synchronous gun when the recoiling components were in battery, or firing position (top right) and when they were in full recoil (center right). After a round was fired the recoiling parts moved rearward until the rammer shoe (top) passed over the rammer catch lever. The rear of the rammer catch lever raised under a spring load and engaged a notch in the bottom of the rammer shoe. As the parts moved into counter-recoil (center) the rammer catch lever prevented the rammer shoe from moving forward. This compressed the rammer spring and at the same time the automatic loader fed a round onto the loading tray. The extractor flange of the round dropped into two slotted rammer levers, which are part of the rammer shoe assembly. The counter recoiling parts continued to move forward and when they were within 0.8 in. of the battery, the cam on the bottom of the loading tray depressed the trip lever. The trip lever rotated the rammer catch lever which released the spring-loaded rammer shoe. The slotted rammer levers catapulted the round forward and were rotated away from the round near the end of the rammer stroke. The round continued forward under its own momentum into the breech. The extractor flange on the round struck the extractors which released the spring-loaded breech block. The breech block moved upward behind the round forcing the round firmly into the breech. At the top of its stroke, the breech block tripped the firing pin contained within it and the round was fired. The rammer shoe was released 0.07 seconds before the end of the cycle. The plan was to achieve very close synchronization starting at this point.

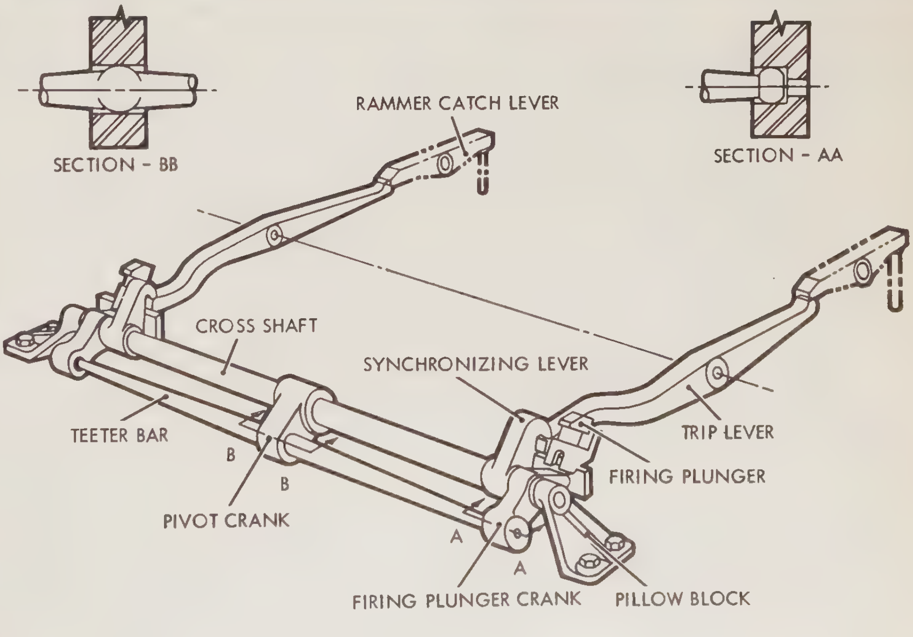


Fig. 6—A teeter bar mechanism (bottom right) was used as the means for achieving a synchronizing device, shown here in the assembled position. A clearance hole was cut through the walls between the two guns and the device mounted on two pillow blocks—one for each gun. A cross shaft supports other members of the device. A firing plunger assembly is mounted to each loader frame. The trip levers were redesigned to make room for the firing plunger assemblies, which must lie in the path of the loading tray cams.

To illustrate the operation of the synchronizing device assume that the firing cycle of one gun is faster than the cycle of the second gun. Also, assume that the faster firing gun has recoiled and is going into counter-recoil. The rammer catch lever engages the rammer shoe and a round, in the loading tray, is engaged by the slotted rammer shoe levers. As the counter recoiling parts move forward, the cam on the bottom of the loading tray depresses the firing plunger, which is contained in a cylindrical housing. The firing plunger rotates the firing plunger crank about the cross shaft. The other end of the firing plunger crank (section A-A) lifts its end of the teeter bar. As this end of the teeter bar raises it carries with it the pivot crank (section B-B). The pivot crank is fixed to the cross shaft so that the cross shaft is rotated. The synchronizing levers also are fixed to the cross shaft and rotate with it until their upper ends contact, but do not move the modified trip levers. This completes the action of the faster gun. As the slower gun moves into battery (firing position) the cam on the bottom of the loading tray depresses its firing plunger and rotates its firing plunger crank. This raises its end of the teeter bar which carries with it the pivot crank. The pivot crank rotates the cross shaft which, in turn, rotates the synchronizing levers. The synchronizing levers are in contact with the modified trip levers. This additional movement depresses the trip levers, rotating the rammer catch levers which release the spring-loaded rammer shoes simultaneously.

nization should start at the point where the rammer shoes would be released. This would occur 0.07 seconds before a round was fired and was as close as possible to the ideal condition of synchronization at the firing pins when a round was fired.

Teeter Bar Method Used for Synchronization

After the point in the firing cycle at which synchronization should be started had been established, the next step was to design a device to achieve synchronous firing. A teeter bar method of synchronization was decided upon. A basic design was worked out, refined, and then simplified. A working model of the synchronization device was then made (Fig. 6). The device fulfilled all design requirements and had a total weight of six lb.

The basic design drawings were then given to the model shop for fabrication. Several minor design changes were made at this point to facilitate production. All parts were checked carefully to assure conformance with drawing tolerances.

A twin 40mm gun was modified to accept the synchronizing device. All parts were then given to the engineering laboratory for testing. The laboratory designed and built a test stand (Fig. 7) which would put the guns into full recoil and release them either singly or together. The test stand also allowed the guns to be brought into battery very slowly so that all working parts could be studied. Initial operation of the guns in the test stand resulted in some minor changes for clearance purposes and ease of installation. After these were made the design was considered ready for actual firing.

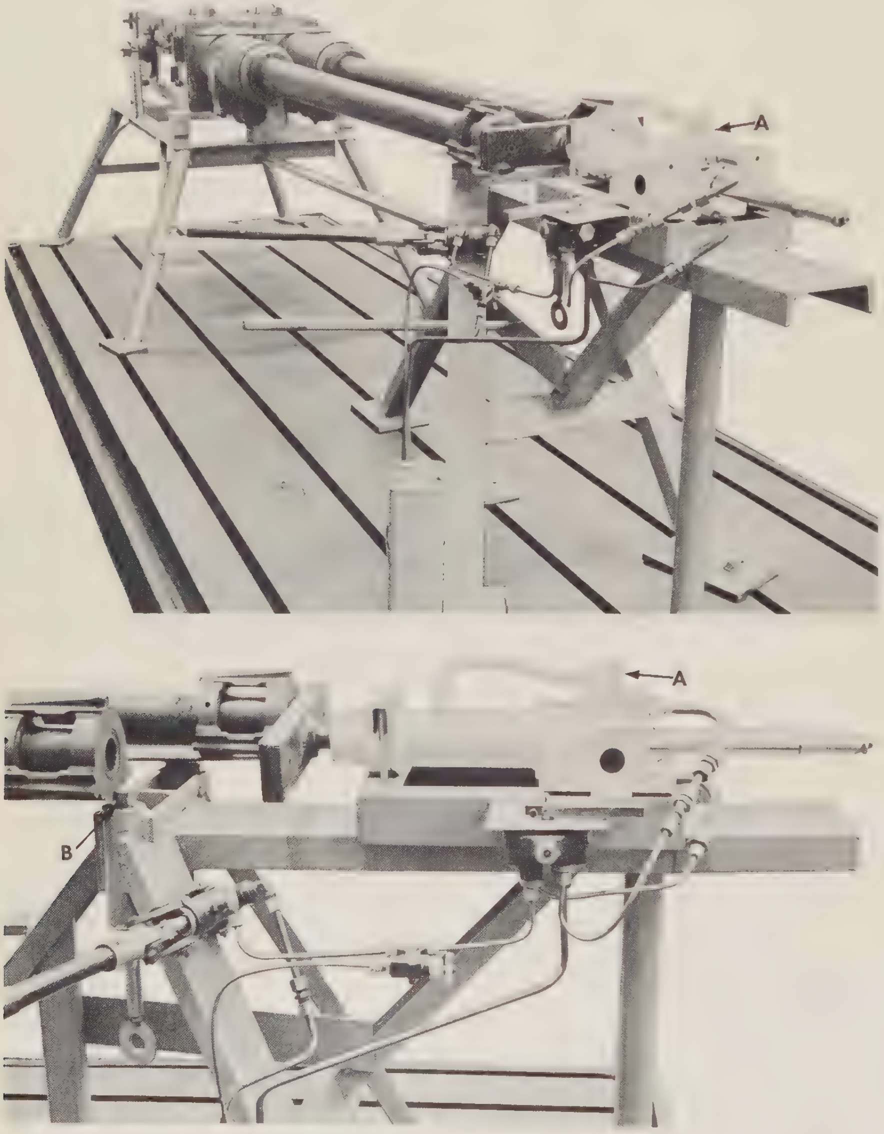


Fig. 7—The test stand designed and built by the engineering test laboratory (top) allowed the guns to be placed into full recoil and then released either singly or together. The guns also could be brought into battery very slowly so that all working parts could be studied. The test stand consisted of a rigid frame to hold the twin 40mm guns, a pneumatic ram *A* to push the guns into recoil, and two stops *B* to hold the gun in recoil while the ram was retracted. The stops could release either or both guns which would then come into battery under the force of the recuperator springs.

Firing Tests Supported Design Expectations

The twin 40mm guns were mounted on a vehicle and were instrumented to record, in relation to time, the following information:

- Gun movement in azimuth
- Gun movement in elevation
- The time the round was fired in each gun.

The instrumentation used recorded the firing of the guns with and without the synchronizing device. Targets also were used to compare firing results with the recorded information.

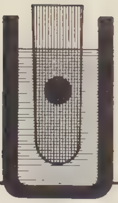
Approximately 1,400 rounds were fired with the guns in synchronous and non-synchronous firing conditions. The guns were fired single-fire, single-fire one gun, single-fire both guns, automatic fire one gun, automatic fire both guns, and various combinations of these firing conditions. During the firing tests no malfunctioning of the synchronizing device occurred. When the guns were fired in the synchronous condition, however, one gun did malfunction due to faulty loading. This event served an important purpose because it showed that even when one gun did not fire the other gun continued to fire, which fulfilled one of the design requirements.

Summary

The actual firing tests showed that dispersion in azimuth was reduced from about 18 mils with non-synchronous fire to less than 2 mils with synchronous fire. Dispersion in elevation was reduced from about 4 mils with non-synchronous fire to about 2 mils with synchronous fire. The maximum variation between synchronized rounds was 0.03 seconds.

After all preliminary test work was completed by Cadillac Ordnance Plant engineers, the project was then turned over to the U.S. Army for final acceptance testing.

Magnetic Test Accurately Compares Heat Extraction Properties of Quenching Media



By EDWARD A. BENDER
and HARRY J. GILLILAND
General Motors
Process Development Staff

A problem which has plagued heat treaters for years has been securing the correct rate of quenching to meet the specifications of various steels used in industry. Engineers of the Process Development Staff, located at the GM Technical Center, have devised a *magnetic quench test* to compare the heat extraction properties of quenching media. This test measures the time required for a medium to cool a metal to its Curie point, where it then regains the magnetic properties which it lost through superheating. The test has given excellent results, and a portable apparatus is now being developed. The equipment also can be used to investigate the heat extraction properties of other substances, such as cutting fluids.

Quenchant speed measured by time required to cool a metal to its Curie point

One of the most important requirements in the heat treatment of steel is that of extracting heat from the metal so that desired physical properties are obtained. This process of heat removal is more commonly referred to as quenching, and the attainment of the desired rate of quenching to meet the specifications of various steels used in industry has plagued heat treaters for years. Engineers of the Process Development Section of the GM Process Development Staff, recognizing the need for a method to compare accurately the heat extraction properties of the numerous quenching media available on the market today, devised the *magnetic quench test*. This test makes use of the property of certain metals to lose their magnetism when heated above a temperature known as the Curie point and to regain it when cooled below this temperature.

Any magnetic material having a suitable Curie temperature can be used in the test. In preliminary work, various steels were investigated by Process Development engineers; however, pure nickel was selected for repeated testing because of its non-scaling characteristics and its resistance to cracking upon continuous re-heating and quenching. The use of pure nickel precludes the requirement of an atmosphere controlled furnace, if such equipment is not readily available. As a result of extensive experimentation, the nickel for use in the test was made into a sphere with a diameter of 7/8 in. and a weight of approximately 50 grams (Fig. 1).

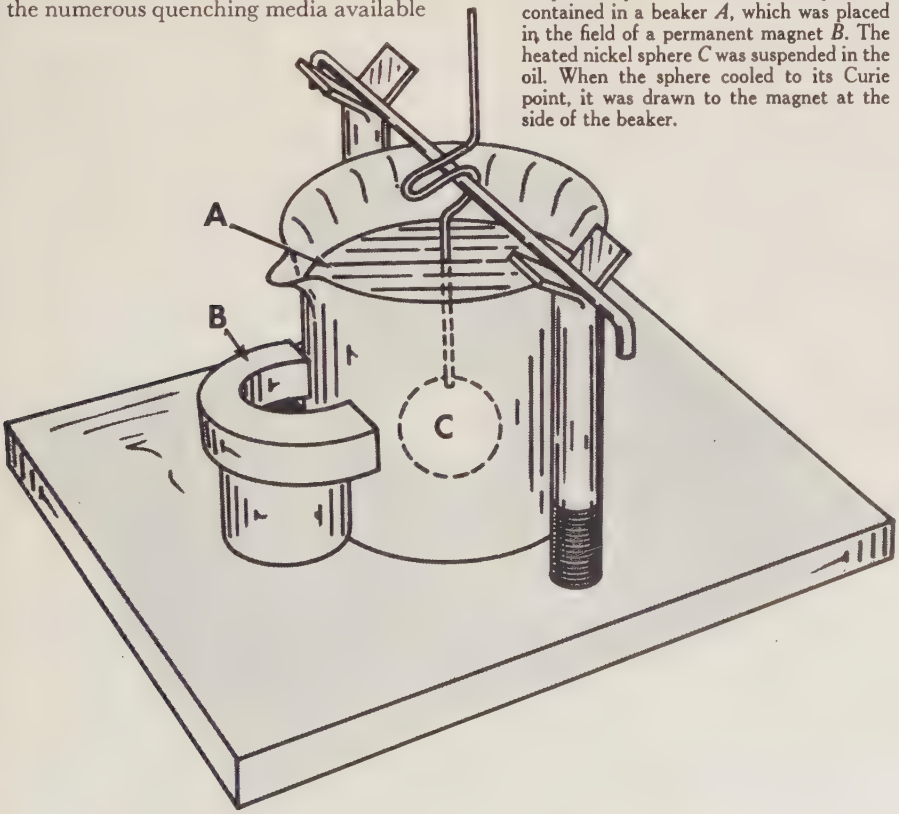


Fig. 1—The original magnetic quench test stand apparatus was comprised of very simple components. The oil sample was contained in a beaker *A*, which was placed in the field of a permanent magnet *B*. The heated nickel sphere *C* was suspended in the oil. When the sphere cooled to its Curie point, it was drawn to the magnet at the side of the beaker.

The magnetic quench test was performed by heating the nickel sphere to 1,600°F, either in air or a controlled atmosphere. (So that data could be obtained and correlated under varying conditions, nickel balls were run without protection, with endothermic gas, and in a nitroneal atmosphere of low hydrogen content.) After uniformity of heat was obtained at 1,600°F, the nickel sphere was quenched in the oil sample under test, which was within a magnetic field.

The time required for the nickel to cool from the furnace temperature to its Curie point, at which instant it is attracted by the magnet, is a measure of the heat extraction power of the quenchant. The Curie point of pure nickel is 670°F, a temperature which occurs below the nose of the familiar "*S*" curve in the isothermal transformation diagrams for most steels.

Test Method Results Substantiated by Hardness Test Checks

To evaluate the test method, six premium oils, two straight mineral oils, and the same mineral oils with special proprietary additives were used as samples for comparison. The premium oils were identified by the symbols *A* through *F*, and the mineral oils by their commercial

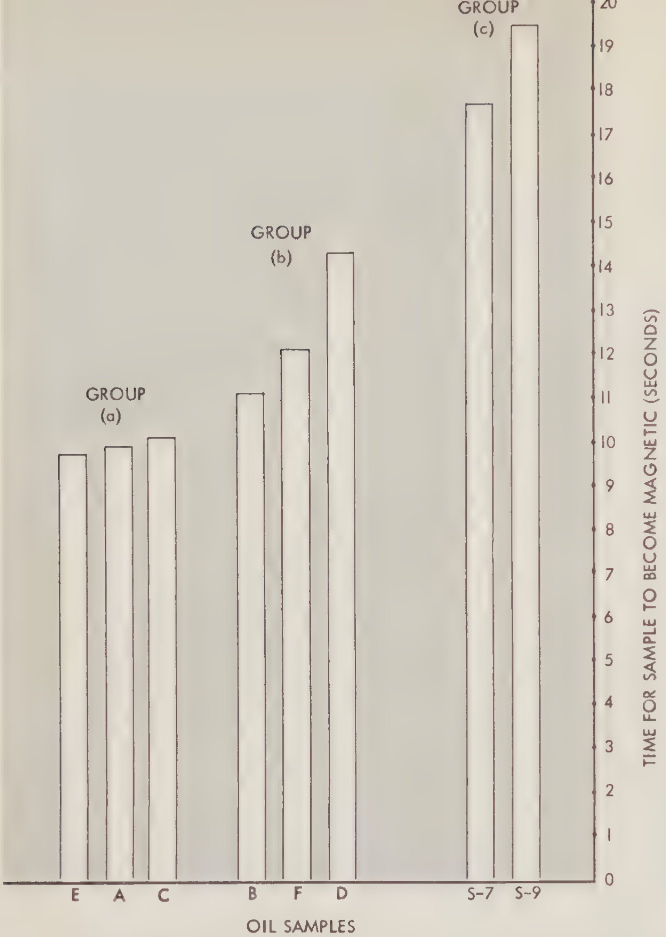


Fig. 2—This graph illustrates the time required for each oil sample to cool the nickel sphere to its Curie point. A nickel sphere having a mass of 50 g was suspended in 200 cc of coolant at room temperature. The oils in groups (a) and (b) are premium oils. Two straight mineral oils comprised group (c).

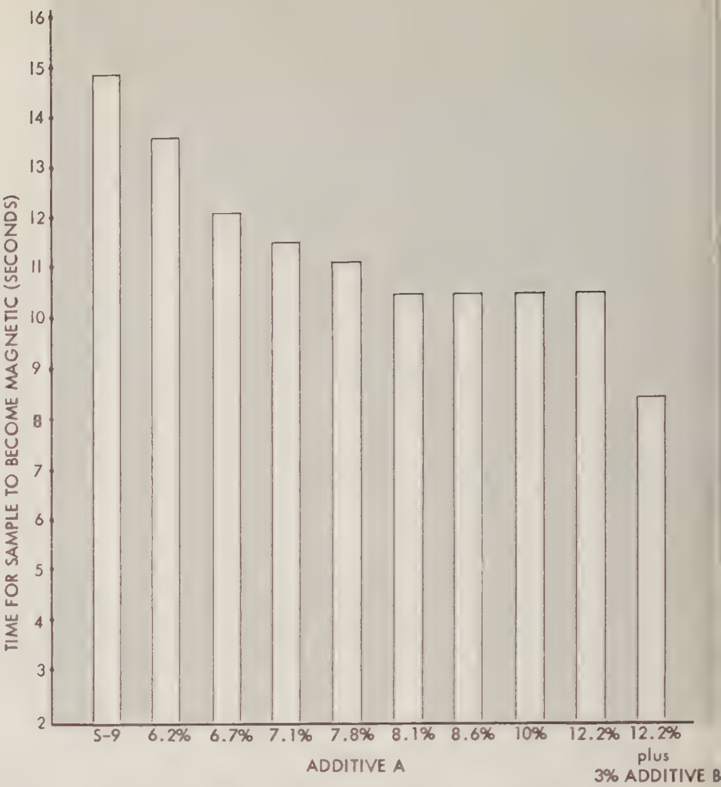


Fig. 3—The effect of an additive to improve the heat extraction properties of S-9 mineral oil showed that any additions of additive "*A*" in excess of 8.1 per cent did not increase the quench speed, except when a second additive "*B*" was added. This test was conducted with a nickel sphere of 40 g mass and an initial volume of 180 cc of still oil at room temperature.

designations, *S-7* and *S-9*. A volume of 200 cu cm was used for test purposes.

The oils were evaluated by measuring the time required for the standard nickel ball to regain its magnetism. Thus, a direct comparison was readily obtained: the faster the quenching speed of an oil, the shorter the time required for the nickel to regain its magnetism. Good test results were established by several hundred repetitive tests in still oil at room temperature (Fig. 2).

The classification of the oils and their relative quenching speeds has been substantiated further by agitating the oils up to a velocity of 300 ft per min and heating them to a temperature of 130°F.

The magnetic quench test also was used to study the effect of special proprietory additives to straight mineral oil (Fig. 3). Additions in excess of 8.1 per cent of the proprietory compound used did not increase the quench speed of the oil, except when a second compound was introduced. However, the ultimate speed did not reach that exhibited by the best premium oils. At the time the tests were

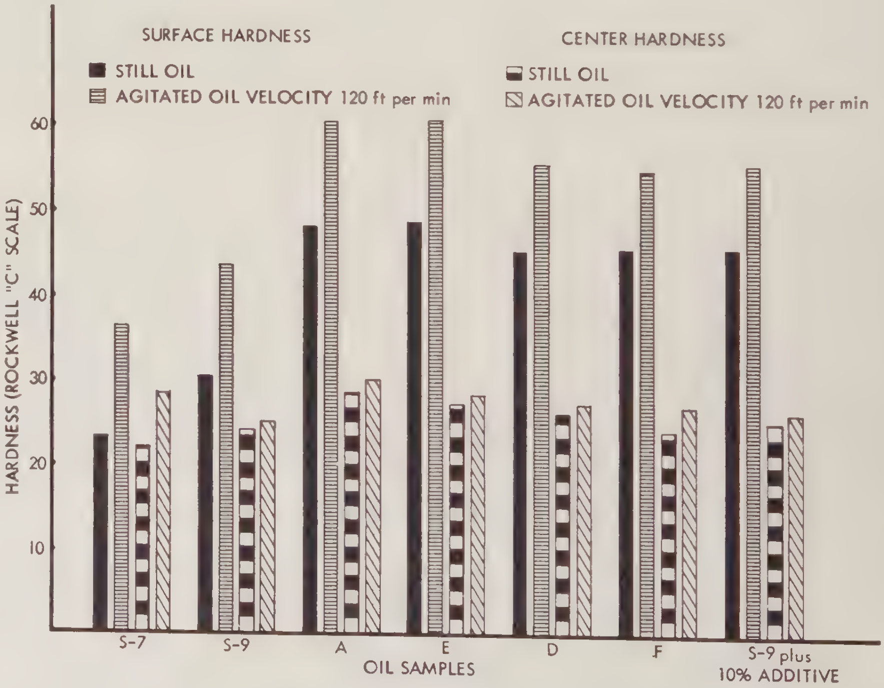


Fig. 4—Shown here is the comparative hardness at the surface and center of S.A.E. 1046 steel bars quenched in various premium and mineral oils, under both still and agitated conditions. This particular test was performed to correlate results found by the magnetic quench test.

Table I—Summarized here are the results of three different tests performed to compare the quenching powers of premium and straight mineral oils. The results indicate the consistency of the magnetic quench test, when compared to the as-quenched hardness, and the inconsistency of the two commercial test methods *A* and *B*. The quenching speed of the various oils decreases from left to right.

METHOD OF TEST	CLASSIFICATION WITH DECREASE IN SPEED	
	Premium Oils	Straight Mineral Oils
Magnetic Quench	E A C B F D	S-7 S-9
As-Quenched Hardness	(E A) (C B) F D	S-9 S-7
Test A	F E D C A B	S-9 S-7
Test B	(F E) C (A D) B	(S-9 S-7)

( ) Indicates oils gave identical results

conducted, a 40-g nickel sphere and 180 cu cm of quench oil were being used. Thus, another advantage of the magnetic test was realized—all results will be relative so long as the nickel specimen and oil sample volume remain constant.

Because of the importance of correlating magnetic quench test results with operating practices, transverse hardness tests were made on S.A.E. 1046 steel quenched in the various oil samples. The test bars were 7/8 in. in diameter and 3 in. long, with two surfaces 180° apart that were ground flat prior to heat treatment to obtain accurate surface hardness measurements.

The test pieces were austenitized at 1,500°F in an electric furnace with an atmosphere of endothermic gas. Quenching was performed in two liters of oil, both still and agitated with an oil velocity of approximately 120 feet per minute. Each test bar was sectioned and transverse hardness checks were made (Fig. 4).

Excellent correlation was found to exist between the properties of the oils as shown by the magnetic quench test and the surface and center hardness test.

The magnetic quench test also was compared with two commercial test procedures used in industry today. As a result of exhaustive tests, the following conclusions were drawn (Table I):

- results of the two commercial tests did not correlate with the transverse hardness tests
- results of the commercial tests were not reproducible
- one of the commercial tests is difficult to perform because it requires two operators.

Principle Can be Applied in Several Ways

An electrical device has been developed by the Process Development Section for use by other organizations. This device, the *Magnetic Quenchometer*, simplifies the method of test and eliminates the element of human error in repeated testing (Fig. 5).

Another device consisting of two coils, a balanced bridge network, an amplifier, and an electric timer is being studied for portable use in production quenching systems. This device will facilitate a true test of the quench oil under actual operating conditions.

Conclusion

The magnetic quench test is not limited to tests of oil alone. It also can be utilized to evaluate the heat extraction rates of gases and salts, the inhibiting effect of sludge build up, the effect of the surface condition of heat treated parts on quenching, and the inhibiting effect of salts adhering to the piece upon quenching. An evaluation of cutting fluids is another field within the scope of this test.

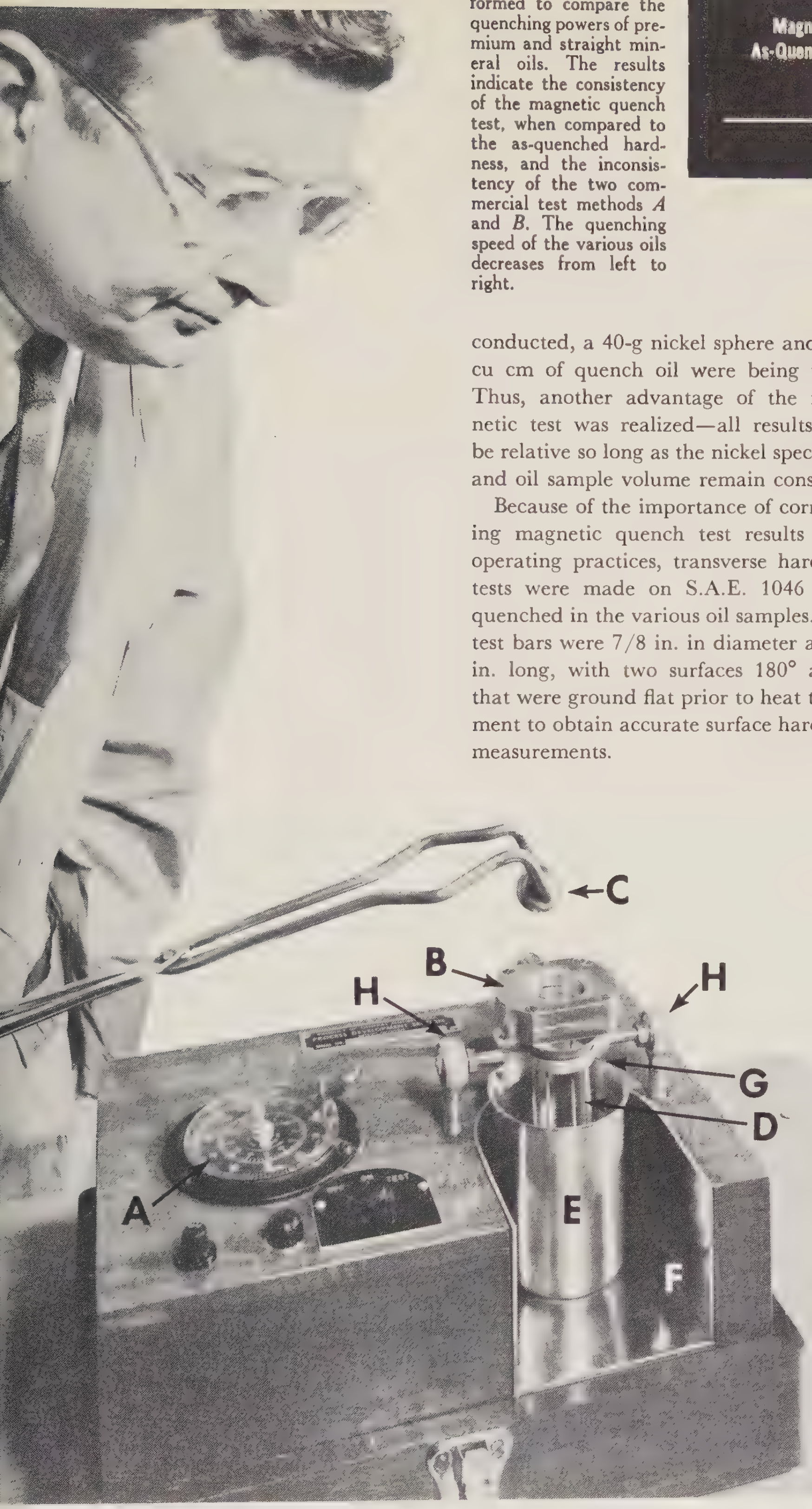
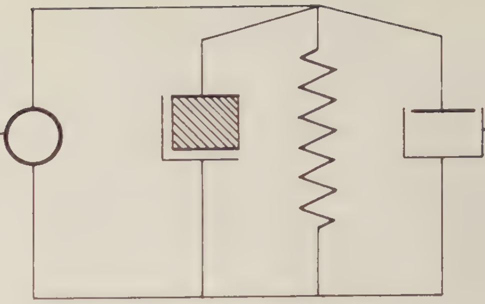


Fig. 5—To simplify the magnetic quench test method and eliminate human error in testing, Process Development Staff engineers developed the *Magnetic Quenchometer* shown here. A timer *A* is actuated by a photocell located in the photocell housing *B*, when the nickel sphere *C* passes through the housing bore into the cage *D*. The cage holds the sphere in the oil sample container *E*. When the cage and sphere are attracted to the side of the vestibule *F*, which contains the quenchant sample, the timer is shut off. The cage is supported by a yoke *G*, which is held by two, rod end aircraft-type bearings *H*. The interval recorded by the timer is a measure of the cooling ability of the quenchant sample.

Mechanical Vibration Analysis by Electrical Circuit Analogy



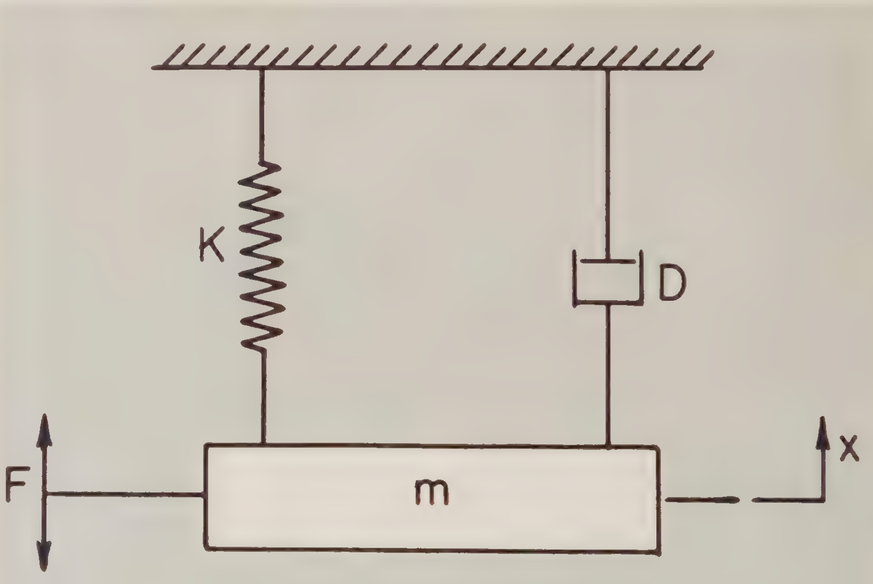
During the design and development phase of a multi-cylinder Diesel engine, torsional vibration problems must be solved to determine resonant frequencies and vibration amplitudes. The solution to these problems can be a complicated and wearisome matter, especially when more than two or three mass-spring systems are involved. To reduce the complexity and the tedious and time-consuming labor involved with such problems, the electro-mechanical analogy concept is applied. This analogy allows an engineer to think of mechanical systems in terms of electrical circuit theory. Electrical networks composed of capacitors, inductors, and resistors can be arranged and studied in lieu of mechanical networks composed of masses, springs, and friction elements. The validity of this analogy rests on the formal similarity of differential equations describing the mechanical and electrical systems being studied. The analogy theory, therefore, is a precise relationship established on a firm mathematical basis. The practical application of the theory allows a simple and inexpensive approach to the analysis and solution of a complex vibration problem.

Analogy can be defined as a process of logic—a process where the similarity of relationships between various things is noted rather than the similarity of things themselves and where it is inferred that the behavior of one thing can be predicted from the behavior of another which has similar basic attributes. This idea is very useful in solving vibration problems because the basic relationships between elements in mechanical vibration problems are the same as those relationships in certain electrical circuits. Once the basic relationships have been recognized it is then possible to solve mechanical vibration problems directly by the powerful methods developed in electrical network theory and also by experimental methods using electrical circuits.

Analogy Concept Simplifies Problem Analysis

The experimental method of utilizing the analogy concept works as follows. An electrical circuit is first constructed in such a way that a mechanical system composed of inertias, springs, and dampers is represented by electrical condensers, inductors, and resistors. Measurements of voltages and currents, made during suitable tests on the electric circuit, can then be translated into mechanical quantities such as velocities and forces applicable to the mechanical arrangement, which the electrical circuit is supposed to represent.

Once the basic correspondence between the electrical and mechanical systems has been established, it then becomes a simple matter to obtain the results of "vibration tests." Such tests may be performed, for example, on a variety of engine and drive arrangements. There is no necessity for changing any mechanical parts on the one hand or making extensive calculations on the other. Instead of replacing mechanical parts between tests, it is only necessary to replace a condenser here or an inductor there and then repeat the test. The results of such tests appear immediately in terms of voltages as soon as the system constants are changed. In this way a designer, using simple and inexpensive materials,



$$m\frac{d^2x}{dt^2} + D\frac{dx}{dt} + Kx = F(t) \qquad (1)$$

Fig. 1—The vibratory behavior of a simple translatory system can be described by the differential equation of motion shown here. The system is composed of a weight of mass m which has a linear displacement x, a spring constant of stiffness K, and a viscous friction dashpot of damping constant D. The system is acted upon by an external force $F(t)$. Equation (1) may be stated verbally as follows: At any instant an externally applied force must be balanced by the sum of the inertia force, the damping force, and the spring force.

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A review of the theory behind electro-mechanical analogy

acquires rapidly a feeling for the problem as a sound design is approached.

Mechanical and Electrical Systems Have Similar Differential Equations

To illustrate and develop the analogy concept, use will be made of the striking similarity between the dynamic behavior of translatory and torsional spring-mass systems.

The vibration behavior of a translatory system (Fig. 1) consisting of a weight of mass m, a spring constant of stiffness K, and a viscous friction dashpot of damping constant D, acted upon by an externally applied force $F(t)$, can be described by the following differential equation of motion:

$$m\frac{d^2x}{dt^2} + D\frac{dx}{dt} + Kx = F(t). \quad (1)$$

Equation (1) is simply a statement of the dynamic equilibrium of forces acting on m, written in terms of the linear displacement x of the mass and the independent variable time t.

In a like manner, a torsional system (Fig. 2) consisting of a flywheel of mass moment I, a torsional spring of torsional rigidity k, and a viscous torsional damper of damping constant d, acted upon by an external torque $T(t)$, can be described by the following differential equation:

$$I\frac{d^2\Theta}{dt^2} + d\frac{d\Theta}{dt} + k\phi = T(t). \quad (2)$$

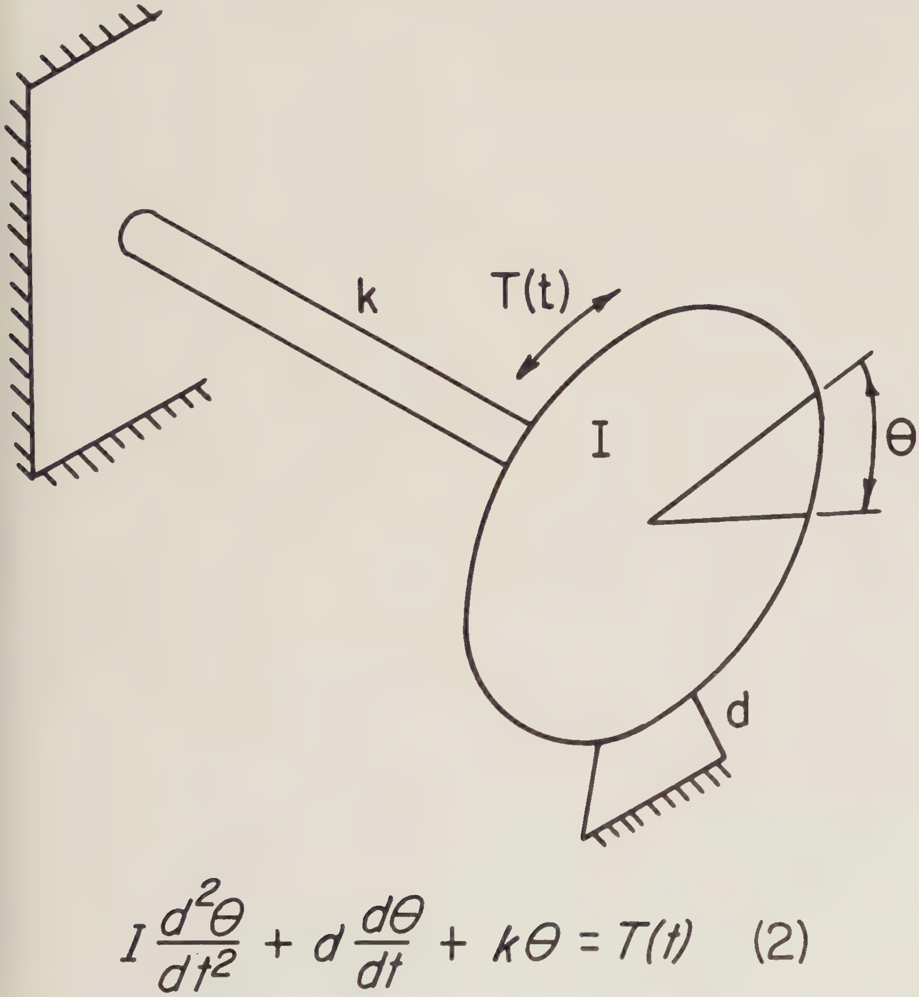

k
T(t)
I
Θ
d
$I\frac{d^2\theta}{dt^2} + d\frac{d\theta}{dt} + k\theta = T(t) \quad (2)$

Fig. 2—The differential equation describing the torsional system shown here is similar in form to the differential equation (1) for a translatory system (Fig. 1). The torsional system here consists of a flywheel of mass moment I, a torsional spring of torsional rigidity k, and a viscous torsional damper of damping constant d. The system is acted upon by an external torque $T(t)$. Equation (2) states the dynamic equilibrium of torque in terms of angular displacement Θ of the flywheel mass and the independent variable time t.

Equation (2) is a statement of dynamic equilibrium of torques in terms of angular displacement Θ of the flywheel mass and the independent variable time t.

The similarity in form between equations (1) and (2) is readily apparent. It is reasonable, therefore, that a single equation, such as equation (1), can be used to describe both the translatory and torsional system, provided that the proper adjustments in terminology are made.

In addition to describing the translatory and torsional systems with a single differential equation, a single idealized schematic diagram (Fig. 3), suggested by Professor F. A. Firestone[1], also can be used.

To simplify subsequent equations and comparisons, equation (1) will be rewritten in terms of velocity v and the independent variable time t as follows:

$$m\frac{dv}{dt} + Dv + K\int v\,dt = F(t). \quad (1a)$$

The preceding equations have been written to show that if the terminology is adjusted to the particular system being calculated, the formal solution of equations (1) or (2) can be applied with equal validity in either system. Returning to the definition of analogy it can be said, therefore, that the basic relationship in both the torsional and translatory dynamic systems has been found and is recognized in the identity of the differential equations describing the motions in these two systems.

Equations also can be written to describe the vibratory behavior of voltages in an a-c electrical circuit (Figs. 4a and 4b). If Kirchoff's law of currents is applied to the circuit of Fig. 4a the following equation results:

$$C\frac{de}{dt} + \frac{e}{R} + \frac{1}{L}\int e\,dt = i(t). \quad (3)$$

In a like manner, Kirchoff's law of voltages can be applied to the circuit of Fig. 4b to give the following equation:

$$\frac{1}{L}\frac{di}{dt} + iR + \frac{1}{C}\int i\,dt = e(t). \quad (3a)$$

The similarity of equations (3) and

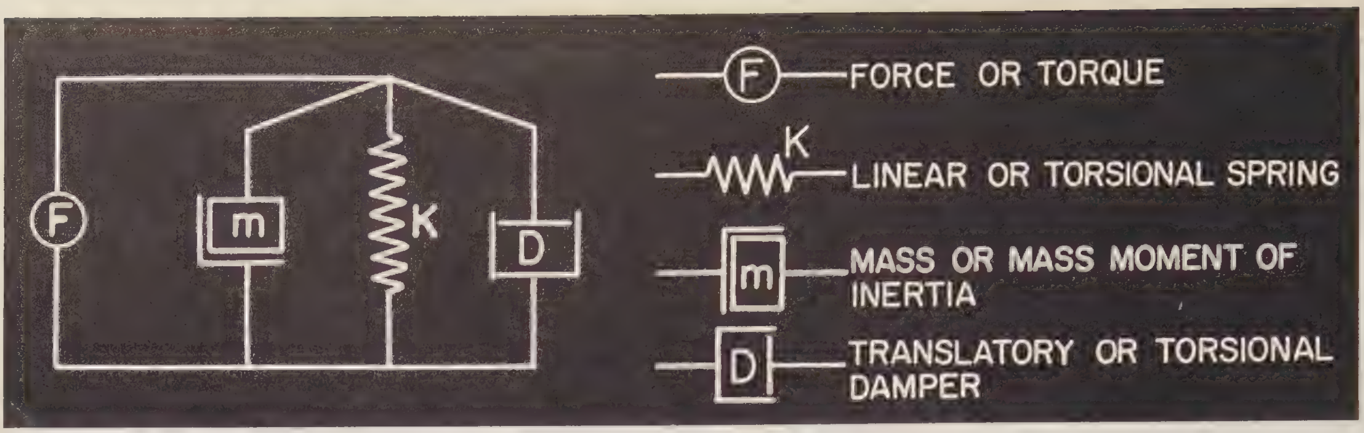

F
m
K
D
F — FORCE OR TORQUE
K — LINEAR OR TORSIONAL SPRING
m — MASS OR MASS MOMENT OF INERTIA
D — TRANSLATORY OR TORSIONAL DAMPER

Fig. 3—Translatory and torsional systems can be described by the single idealized diagram shown here just as they can be described by a single differential equation. The diagram is constructed by connecting the "terminals" of the various mechanical elements shown in Figs. 1 and 2. It should be kept in mind that the inertia force which characterizes a weight of mass m is described in terms of an absolute acceleration so that one terminal of the mass must be attached to the frame of reference for that acceleration (the earth, in most cases).

(3a) to equation (1a) is readily apparent. The forms are identical even though the terms used are different. This equivalence in form can be used to solve mechanical problems by electrical means, provided the proper steps are taken to develop "scale factors" which will allow data to be transformed from one system to another. (In the following discussion, Fig. 4a and equation (3) will be used to illustrate the electrical analogy.)

Variables in Equations Must Be Made Independent of Dimensional Restrictions

In developing the analogy scale factors it will be helpful to write equations (1a) and (3) together and assign to each a specific sinusoidal forcing function as follows:

$$m\frac{dv}{dt} + Dv + K\int vdt = F\sin\omega t \qquad \text{(1a)}$$

$$C\frac{de}{dt} + \frac{1}{r}e + \frac{1}{L}\int edt = i\sin\Omega t. \qquad (3)$$

A system of non-dimensional variables can be set up to permit equating each term in equation (1a) to the corresponding term in equation (3). From this, a set of non-dimensional constants can be derived which can then be used to arrange a consistent analogy.

The variables in the equation can be made non-dimensional, that is, independent of dimensional restrictions. This can be done by dividing the variables by quantities having the same dimensions as the original variables. The variables v, e, and t, therefore, in equations (1a) and (3) can be replaced by non-dimensional variables V, E, and T_m and T_e. Each of these non-dimensional variables can be expressed in equation form as follows:

$$V = \frac{v}{s} \qquad (4)$$

where

s = any velocity (Dimensional analysis shows that V is non-dimensional because the right hand member, v/s, is a velocity divided by a velocity)

$$E = \frac{e}{P} \qquad (5)$$

where

P = any voltage.

Also,

$T_m = \mu t$ (in mechanical system) (6)

and

$T_e = \nu t$ (in electrical system) (7)

where

μ and ν = frequencies having dimensions 1/time, so that T_m and T_e are non-dimensional.

The following functions derived from the above equations also can be substituted into equations (1a) and (3):

$$\left.\begin{aligned} dv &= sdV \\ dt &= \frac{dT_m}{\mu} \\ de &= PdE \\ dt &= \frac{dT_e}{\nu} \end{aligned}\right\} \qquad (8)$$

Equations (1a) and (3) may now be written, with the appropriate substitutions, in non-dimensional form as follows:

$$\left.\begin{aligned} &ms\mu\frac{dV}{dT_m} + DsV + K\frac{s}{\mu}\int VdT_m \\ &\qquad = F\sin\frac{\omega}{\mu}T_m \\ &\text{and} \\ &CP\nu\frac{dE}{dT_e} + \frac{1}{r}PE + \frac{1}{L}\frac{P}{\nu}\int EdT_e \\ &\qquad = i\sin\frac{\Omega T_e}{\nu}. \end{aligned}\right\} \qquad (9)$$

Applying a small amount of algebra to equation (9), the following equations will result:

$$\left.\begin{aligned} &\frac{dV}{dT_m} + \left(\frac{D}{m\mu}\right)V + \left(\frac{K}{m\mu^2}\right)\int VdT_m \\ &\qquad = \left(\frac{F}{ms\mu}\right)\sin\left(\frac{\omega}{\mu}\right)T_m \\ &\text{and} \\ &\frac{dE}{dT_e} + \left(\frac{1}{rC\nu}\right)E + \left(\frac{1}{LC\nu^2}\right)\int EdT_e \\ &\qquad = \left(\frac{i}{CP\nu}\right)\sin\left(\frac{\Omega}{\nu}\right)T_e. \end{aligned}\right\} \qquad (10)$$

To obtain a consistent analogy, equations (10) should be interchangeable. This can be accomplished by establishing the following equations made up from the non-dimensional constants shown in the parentheses of equations (10):

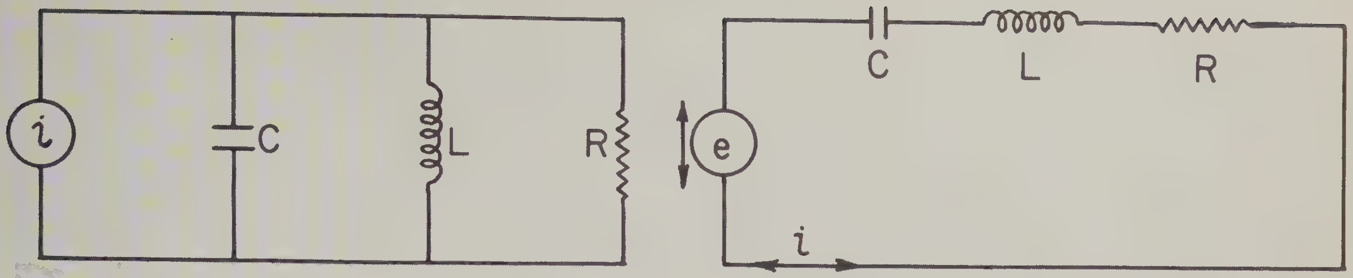
$$\frac{D}{m\mu} = \frac{1}{rC\nu}, \text{ or } (Dr)\left(\frac{c}{m}\right)\left(\frac{\nu}{\mu}\right) = 1 \qquad (11)$$

$$\frac{K}{m\mu^2} = \frac{1}{LC\nu^2}, \text{ or } (KL)\left(\frac{c}{m}\right)\left(\frac{\nu}{\mu}\right)^2 = 1 \qquad (12)$$

$$\frac{F}{ms\mu} = \frac{i}{CP\nu}, \text{ or } \left(\frac{F}{i}\right)\left(\frac{C}{m}\right)\left(\frac{P}{s}\right)\left(\frac{\nu}{\mu}\right) = 1 \qquad (13)$$

$$\frac{\omega}{\mu} = \frac{\Omega}{\nu}, \text{ or } \left(\frac{\omega}{\Omega}\right)\left(\frac{\nu}{\mu}\right) = 1. \qquad (14)$$

These non-dimensional constants can be used in assigning specific values in analyzing problems as soon as the values of the original variables v, e, and t have been determined. Using equations (4) and (5) and realizing that V and E are equivalent in the analogy, it is apparent that the ratio P/s in equation (13) can be regarded as equal to e/v. Likewise, the ratio ν/μ is equal to the ratio of electrical time to mechanical time, as



FROM KIRCHOFF'S LAW OF CURRENTS:

$$C\frac{de}{dt}+\frac{e}{R}+\frac{1}{L}\int e\,dt=i(t) \qquad (3)$$

(a)

FROM KIRCHOFF'S LAW OF VOLTAGES:

$$\frac{1}{L}\frac{di}{dt}+iR+\frac{1}{C}\int i\,dt=e(t) \qquad (3a)$$

(b)

Fig. 4—Differential equations describing the vibratory behavior of a-c electrical circuits have a form similar to the differential equations for translatory and torsional systems. Differential equation (3), describing a parallel electrical circuit (a) having a capacitance C, inductance L, and resistance R and excited by current i, is obtained by applying Kirchoff's law of currents. In a like manner, Kirchoff's law of voltages can be applied to a series electrical circuit (b) excited by a voltage e to obtain the differential equation (3a).

inspection of equations (6) and (7) show. With this, the theoretical analogy is complete.

The practical problem of establishing a specific electrical arrangement to fit a specific mechanical problem can be carried out by first establishing, arbitrarily, a sufficient number of the ratios (or products) in equations (11) thru (14) so that solutions may be found for the others and then solving for the necessary quantities.

Practical Application Requires a Few Preliminary Assumptions and Calculations

To illustrate the practical application of the analogy concept, assume that an electrical model of the arrangement shown in Figs. 2 and 3 is constructed and the following mechanical constants assigned:

m = 23.9 in.-lb sec^2
K = 150 (10)^6 in.-lb per radian
D = 180 in.-lb sec per radian
F = 10^4 in.-lb.

The electrical model will have the form shown in Fig. 4a and a commercially available audio oscillator will be used to provide the forcing function i. It will be necessary, therefore, to establish the electrical frequency at a higher value than the mechanical frequency—say, 10 to 1. This makes ν/μ (or Ω/ω) in equation (4) equal to 10.

For similar reasons, i should be equal to approximately 0.001 amperes so that F/i = 10,000/0.001 or 10^7 in equation (13). Using an inductor of 0.120 henries, the constant KL in equation (12) can be set at 18(10)^6. With these assumptions, the following values can be calculated:

C = (0.0133) (10^{-6}) farads
r = 10^6 ohms
$\frac{v}{e}$ = 0.0556.

With this set of values constructed and with inductors for springs (shafts), capacitors for inertias, resistors for dampers, a sine wave generator for a forcing function, and such common laboratory instruments as vacuum tube voltmeters and oscilloscopes, the equipment necessary to start evaluating the vibration performance of the mechanical system is complete.

Resonant frequencies now can be determined readily without the need for solving any differential equations. Velocity amplitudes can be measured with an accuracy depending on the quality of the electrical components, which is frequently as good or better than the accuracy with which the values in the mechanical system are known.

Summary

The application of electro-mechanical analogy to mechanical vibration problems decreases appreciably the complexity and time-consuming labor usually associated with designs in this field. Once the electrical model of the mechanical system under analysis is arranged and all constants established, an evaluation of the system (and alternative designs) can be made rapidly in terms of resonant frequencies and vibration amplitudes.

The electro-mechanical analogy concept has many practical applications. One application of the theoretical concept is in the solution of multi-cylinder, Diesel engine torsional vibration problems, which will be the subject of a future paper.

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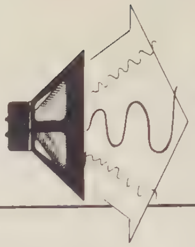
A Discussion of Some Factors Affecting Reproduced Radio Sound in an Automobile



By **BERTRAM A. SCHWARZ**
and **DONALD E. BRINKERHOFF**
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The automobile radio, introduced about 28 years ago, has become a major part of the radio industry and provides a large proportion of the total AM broadcasting audience. When designing an automobile radio several unique factors must be taken into account—factors which designers of home radios need not consider. Because of the environmental conditions in an automobile, that is, ambient noise and interior acoustical characteristics, the radio system must be designed to compensate for disadvantages inherent with the automobile. Also, the effects of the radio on the driver and passengers must be considered in its design. The automobile radio of today has been developed into a highly acceptable product which often aids the driver by increasing alertness and lessening fatigue.

The automobile presents unique acoustical problems

In the design of an automobile radio major consideration is given to the end result—the output sound, which includes its delivery, quality, quantity, and interpretation by the listener. Of prime importance to the designer in achieving this desired end result are the environmental conditions of the car, the radio system, and the effects of these two items on the listener. In this regard, the overall design of the radio is influenced by psychological factors as well as physical factors.

Environment Creates Strict Acoustical Limitations

Radio sound distribution in an automobile is affected by inherent environmental conditions. These conditions result from two sources: (a) ambient noise and (b) the "listening room"—its size, seating arrangement, and acoustics.

Ambient noise is comprised of sounds from the automobile, the engine, the road, the wind, and traffic. Contrary to popular concept, streamlining increases wind noise heard in the automobile. Before automobiles were streamlined the bow wave broke some distance away from the car. With streamlining, the noise-producing turbulence is in the slip stream hugging the car and is close to the occupants' ears.

The ambient noise level in the average home is about 43 decibels[1]. In an automobile traveling 65 mph with the windows open, the ambient noise level is approximately 102 decibels (Fig. 1). Using these nearly maximum noise level conditions as a base, and using a ceiling comfortably below the 120 decibel threshold of pain, much of the broadcasted dynamic range is masked off (Fig. 2) These are nearly maximum conditions during which hearing acuity is not great.

There are various ways to deal with the ambient noise problem. One way is to use a loudspeaker having as near an optimum design as possible through better loading and/or reduced grille restrictions. Another way is to use volume companders to limit automatically the dynamic range of response. Such companders have been developed and tested, but they introduce distortion, lessen realism, and are costly. Another method is to use an arrangement which adjusts radio volume automatically with changes in car speed. Such an arrangement was used in GM cars about 18 years ago, but was found to be commercially unsuccessful. The most direct attack on the noise problem is greater soundproofing of the automobile. Improvements in this area are being developed constantly by such groups as the Noise and Vibration Laboratory of the GM Proving Ground[3], with the practical ones being introduced.

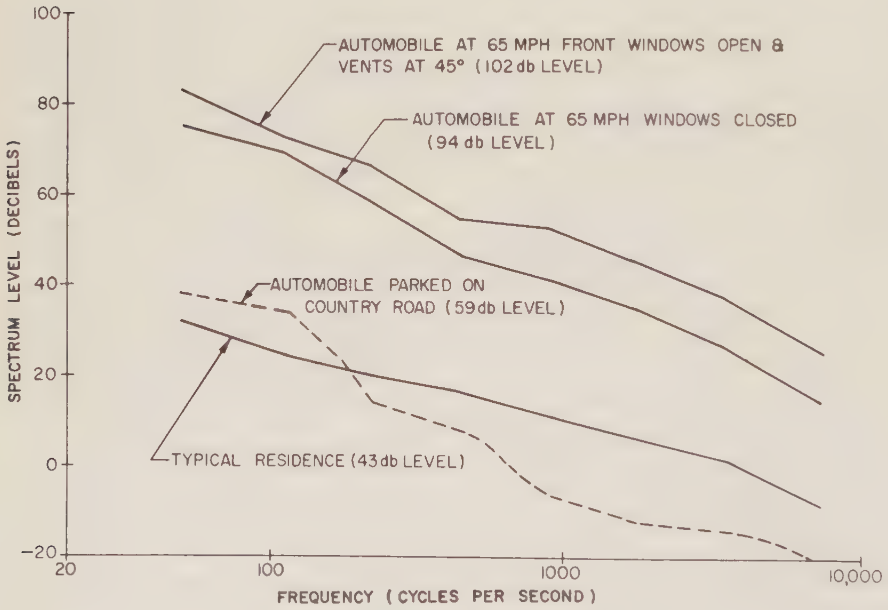


Fig. 1—A comparison of the noise spectra in a home, in a stationary automobile, in an automobile with the windows closed while traveling 65 mph and in an automobile with the windows open while traveling 65 mph shows that noise in the stationary, closed automobile, when compared with the home, is greater at low frequencies but less at high frequencies. The noise in a closed, moving automobile compared with that in a home is greater across the band, especially at the low frequencies. With the windows open in a moving car, the noise is still greater throughout the spectrum with the increase slightly higher at the high frequencies due to wind. These noise data have been converted[2] into resultant masking levels indicated by limits-of-hearing curves (Fig. 2).

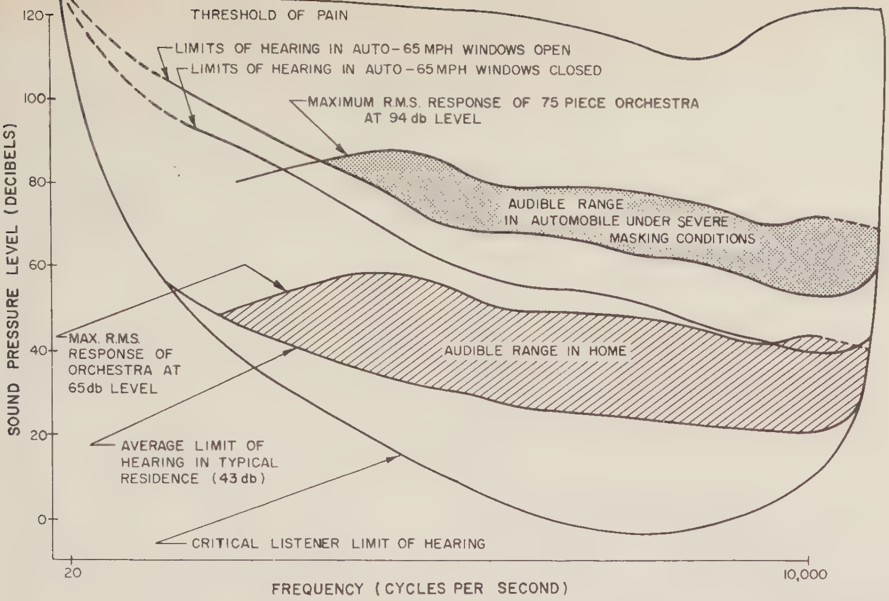


Fig. 2—In a comparison of hearing limits in an automobile and in a living room, an examination of the frequency range shows that a greater range is audible in the home. The fall-off in an automobile is at the bass end. There is less loss of frequency range when the windows are closed and when the automobile is traveling slower.

Two factors regarding an automobile radio are frequency balance and the presence of electrical noises coming through the radio in weak signal pick-up areas. To take care of these two factors it is usual to roll-off the high frequency response of an automobile radio, beginning at about 5,000 cycles. (Roll-off is the rate of reduction in response with frequency, in decibles per octave.) The radio selectivity, or the ability of the receiver to select wanted signals and reject unwanted signals, allows for some of the roll-off.

An examination of the sound pressure level shows that the full dynamic range which is broadcast can come through in the home but in an automobile, under severe environmental conditions, much of the dynamic range is masked-off. The 29 db higher listening level in the moving automobile with the windows open means that either higher undistorted power output is needed from the automobile radio or less transmission loss. Since electrical power output is expensive much of the increase needed can be obtained at less cost acoustically, such as by a more nearly optimum design loudspeaker and through better loading and/or reduced grille restrictions.

In addition to ambient noise, sound distribution also is affected by the environmental conditions of the automobile living room—its size, seating arrangement, and acoustical properties. The smaller room helps deliver the higher volume level required, but increases the problem of distribution. One listener's ears may be a few inches away from the sound source while another's may be six feet or more away.

In the lower part of the automobile body there is much sound absorption, due to passengers' clothing plus the upholstery and carpeting. These materials have an average sound absorption coefficient of 0.75. In the upper part of the car body, particularly hardtop models, the sound absorption is low, due to a considerable amount of glass which has an absorption coefficient of only 0.02. Standing waves are produced here with peak to null intensity variations of the order of 10 decibels. The reverberation time remains relatively short, however, because of the small interior volume. There are fundamental modes of vibration within the body at approximately 70 cps and 110 cps (Fig. 3).

Radio System Adapted to the Environment

In the design of an automobile radio system the basic frequency range required for speech intelligibility[4] is extended to avoid a harsh, irritating tone. Much has been published on the frequency range preferences of listeners[5,6]. Due to the high volume level required and the close proximity of sound source to listener in an automobile, a smooth frequency response characteristic is of utmost importance to avoid auditory fatigue and distraction.

In addition to high power output, the automobile loudspeaker must have high efficiency. The total efficiency of a loudspeaker is comprised of the efficiencies of electrical to mechanical and mechanical to acoustical transfers of energy. The motor system of the loudspeaker usually determines the efficiency of electrical to mechanical transfer of energy.

The efficiency of mechanical to acoustical transfer of energy is determined by the effective loading of the diaphragm and the combination of diaphragm area and excursion. Of the latter combination, the one extreme is a large area, small excursion diaphragm, such as the electrostatic loudspeaker. Such a configuration has advantages for use in an automobile. The early development of this type of automobile loudspeaker was revived because it was believed that newer materials for the dielectric might improve its effectiveness. The speaker, however, still did not have sufficient bass response or satisfactory life outdoors, despite improved dielectric materials. Continuing work resulted in the present household electrostatic "tweeter."

The other extreme of diaphragm area and excursion combination is a small area, large excursion cone diaphragm speaker with increased driving power which, in turn, increases the volume current. This can be shown by the following acoustical equation:

$$P_a = (u^2)\ (R_r)$$

where

P_a = acoustical power
u = volume current
R_r = radiation resistance.

The advantage of the electrostatic speaker is the increased radiation resistance. The advantage of the small area, large excursion cone speaker is the increased volume current. Difficulty in preserving linearity with a large excursion speaker increases problems of harmonic and inter-modulation distortions. The optimum combination of cone area and excursion for this service, therefore, is about that of the usual, larger automobile loudspeaker. Since the mounting space available for the diaphragm in an automobile is almost always rectangular, the elliptical dynamic speaker having maximum diaphragm area was developed. This type of speaker was introduced in the automobile about 19 years ago and is now the most popular type.

Loudspeaker Location Influences Efficient and Uniform Sound Delivery

The efficiency and tone characteristics of an automobile radio are impaired by a grille with restricted openings in front of the loudspeaker, particularly if the openings are not proportionally distributed. The tone is then restricted, rough, ragged, and unnatural. Efficiency and tone impairments also result if there is an appreciable cavity in front of the loudspeaker cone. The response then is muffled. The combination of the compliance of such a cavity with the acoustic mass of air in the restricted grille openings

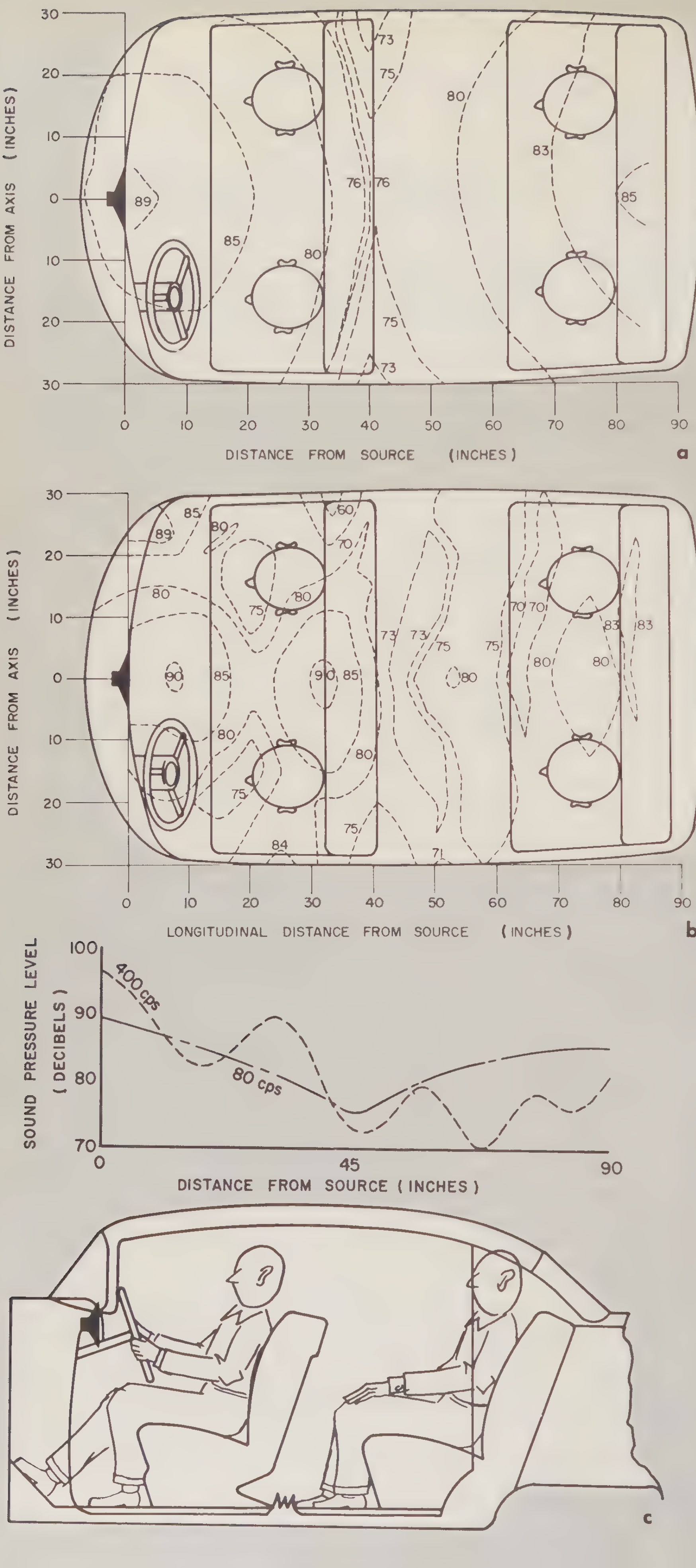


Fig. 3—A plot of sound pressure contours (decibels) for an 80 cps sound from a front location loudspeaker (a) shows that the sound intensity decreases from the front to a mid-point position and then increases again, reaching a level at the back of the car almost equal to the level at the source. The intensity at the ears of the rear seat listeners is about 3 db greater than for the front seat listeners. A plot of sound pressure contours for a 400 cps sound (b) shows a narrower directional pattern due to the decreased ratio of wave length to source diameter along with extreme variations in intensity with position. These variations are one reason that sound pressure measurements in an automobile with various microphone placements are difficult to duplicate and almost impossible to evaluate, even when the frequency is only 400 cps.

The data for the sound pressure contours for the 80 cps and 400 cps frequencies can be combined to show the sound levels through the axis of the body (c). The level of the 400 cps sound rises and falls approximately every 20 in. and the average level decreases as a function of distance to a point approximately 70 in. from the source. The frequency balance, therefore, is tilted toward the bass and the volume is attenuated for those in the rear. A listener located on the axis and close to the source, for example, receives the full treble response and range and, therefore, maximum intelligibility as well as volume. These findings confirm the subjective observations. The frequency balance and volume reaching the rear are satisfactory for less attentive listening. Hence, frequency balance and frequency range are both important, and are influenced by environmental conditions.

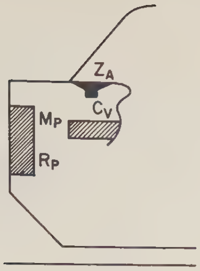
forms a low pass filter, which is most detrimental. Resonance of this front cavity also produces poor transient response and coloration (alterations, other than amplitude, of the original sound caused by the reproducing system).

For efficient bass response an adequate baffle is necessary. This is usually provided by either the package shelf back of the rear seat or the instrument panel. On the instrument panel the average loudspeaker location has the shortest leakage path of the order of 1 ft or 1/15th wave length at 80 cps.

The loudspeaker location is chosen not only for good baffle but also for the most efficient and uniform delivery of sound to the listeners. This is accomplished by locating the speaker in good proximity to the listeners and by the employment of an efficient air coupling.

Air Coupling Efficiency

The loudspeaker is normally located so that advantage is taken of the natural contours of the automobile body. This improves the coupling between the cone and the confined air. First, the location is usually at a high pressure point for most modes of vibration of the interior throughout the audio range. The speaker is then positioned so that a semi-horn



C_V = COMPLIANCE OF "ENCLOSURE"
M_P = MASS OF AIR IN "PORT"
R_P = RESISTANCE OF AIR LOAD ON PORT
Z_A = ACOUSTICAL IMPEDANCE OF FRONT LOAD

Fig. 4—The top of the instrument panel is one of the most effective positions for a loudspeaker in a car. Here the front side of the cone is loaded by the horn with a solid angle, approaching π steradians, formed by the windshield and instrument panel. This results in an increase in efficiency of as much as six decibels higher than with the speaker positioned in the front face of the instrument panel.

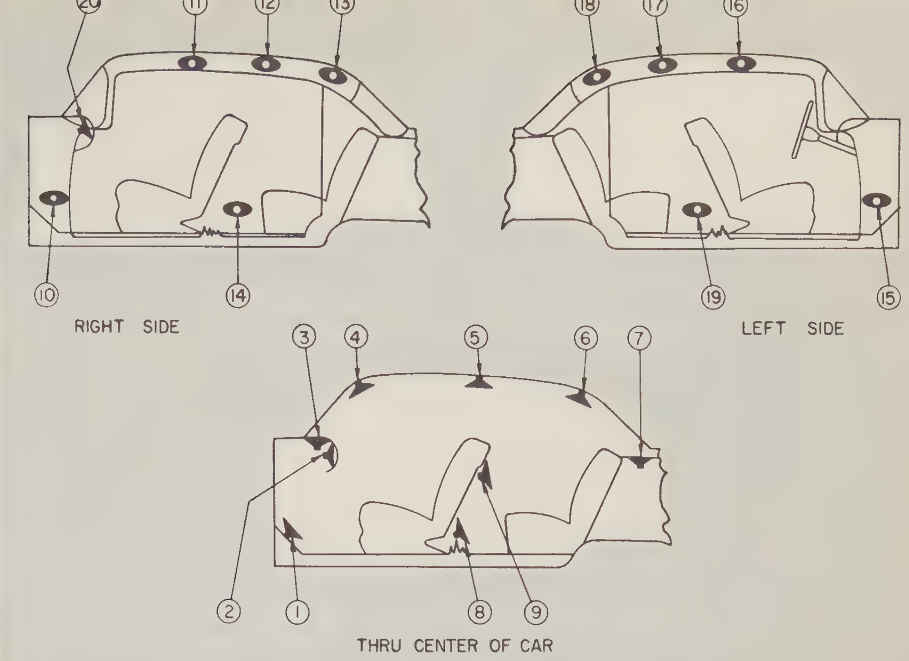


Fig. 5—Twenty loudspeakers were placed in an automobile, as shown here, and were tested singly and in combination. Measurements taken were not completely repeatable, and did not include important psychological factors. As a result, the measurements served only as guides, with final evaluations being made by subjective listening. The speaker locations were in three vertical zones: floor, top, and mid.

The floor zone is farthest from the listeners' ears, and much of the output energy is absorbed in carpeting, upholstery, and passengers' clothing. In addition, there is insufficient room for baffling and/or rear cavity, plus problems with dust, dirt, and mud.

The top zone is closest to the listeners' ears, but distribution uniformity with a single speaker is poor. Also, there is insufficient room, especially for a rear cavity, in present low and trim car bodies. Multiple speakers in the top zone, next to the ear of each listener (positions 11, 13, 16, and 18), provide maximum signal-to-noise ratio, approaching that of headphones. The result, however, is too intrusive, particularly for the driver. Moreover, if a loudspeaker is not centered with respect to both ears, there is a mental urge to adjust the balance, which promotes fatigue. Also, the ability of our binaural hearing system to locate and unmask faint signals we wish to hear while ignoring other sounds is impaired. Therefore, speakers in the top zone should be placed only in the front or back of the car. The preference is determined by the degree of attentive listening desired. For attentive listening the source of sound should be in front to avoid the urge to turn and face the source.

The mid zone is the most satisfactory location. Loudspeakers in the mid zone provide the best degrees of attentive and inattentive listening, the best distribution uniformity, and good signal-to-noise ratio. Here, also, the best baffling and rear cavity possibilities exist.

loading is achieved. This improves the impedance match between the cone and the medium. A good example of this is the location of the loudspeaker on top of the instrument panel (Fig. 4).

It is also possible to couple the back of the cone to the interior to improve the low frequency response. The instrument panel can provide a bass reflex cavity with a loaded port. The resonance of the cavity formed by the instrument panel, cowl with side kick pads, and engine bulkhead and floor, is about 85 cps in a complete body. When a mock-up dummy (similar to the set up shown in Fig. 4) without complete sides, top, floor, and back is measured, the resonance is higher, perhaps as high as 120 cps.

Location of the loudspeaker on the package shelf back of the rear seat provides the best baffle and also a huge rear cavity, due to the luggage compartment. The low frequency efficiency is very high. The resonances of the cavity, however, sometimes produce mid-bass frequency peaks which are too prominent, but can be controlled. Delivery efficiency to the driver of the high and middle frequency ranges needed for intelligibility, however, is reduced.

Multiple Speakers

To investigate the results obtained from loudspeakers positioned in various locations within the automobile, Delco Radio engineers mounted 20 speakers (Fig. 5) and tested them singly and in combination. Final evaluations of the various speaker locations were based on subjective listening. The tests indicated that the mid-zone position of loudspeaker location produced the most satisfactory results.

Today, it is common practice to have at least two speakers in an automobile, usually one in front and one in the rear. This can be extended to four mid-zone speakers, one in each corner of the interior. Such combinations provide excellent sound delivery and good distribution uniformity. There is the pleasant suggestion of stereo on full orchestra, but some confusion and slight reduction in intelligibility on single voice or instrument.

Since the response of a front loudspeaker is different from a loudspeaker located on the package shelf, with its huge rear cavity, a semi-divided range, multiple system results. More definitely divided range, multiple unit systems have been developed to reduce inter-modulation distortion. This technique is unnecessary, however, for the frequency range required in an automobile. Also, such a system, if the "woofer" and "tweeter" are separated physically, can be made satisfactory only for one or two listeners. The use of a response time delay between such divided range, separated loudspeakers presents the interesting possibility of producing the subjective effect that all response is from one source. Such a method, however, would be effective for only one or two listeners.

In multiple loudspeaker systems it is normal practice to have the rear speaker on the package shelf and, therefore, rather close to the ears of the listeners sitting in the back seat. The advantage of the overall system outweighs this distribution disadvantage and, in many instances, this disadvantage is removed by providing a variable fader control to adjust the balance.

Summary

The design of an automobile radio system is influenced not only by physical problems resulting from environmental conditions but also by psychological problems. Compensating factors for the problems involved are that a fixed audience and a known listening room are predictable conditions which can be utilized in the overall design of the radio system. As a result, the automobile radio systems of today are a highly acceptable product which serve as an aid in reducing driving fatigue and increasing alertness.

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6. Olson, H. F., "Frequency Range Preferences of Speech and Music," *Journal Acoustical Society of America*, Vol. 19, No. 4 (July 1947), pp. 549-55.

Other related literature in this field includes the following:

Fletcher, Harvey, "Hearing, the Determining Factor for High-Fidelity Transmission," *Proceedings of the I.R.E.*, Vol. 30, No. 6 (June 1942), pp. 266-77.

Sivian, L. J., Dunn, H. K., and White, S. D., "Absolute Amplitudes and Spectra of Musical Instruments and Orchestras," *Journal Acoustical Society of America*, Vol. 2, No. 3 (January 1931), pp. 330-71.

Organization and Function of the GM Patent Section

By GEORGE H. STRICKLAND
Patent Section
Dayton Office Staff

A centralized operation within a decentralized organization

In previous issues of the General Motors Engineering Journal many phases of the patent law have been explained. In many cases actual examples were cited to point out the significance of the specific patent law under discussion. In most instances the examples cited were based on experience gained by the Patent Section lawyers when working with GM personnel regarding patent matters. Questions often have been raised, particularly by young engineers and students in some cases, about how the Patent Section is organized and how it handles patent activities in General Motors.

Patent Section Part of Central Office Staff

General Motors operates quite generally on a decentralized basis with the general manager of each Division responsible for its activities. There are, however, certain activities within GM which experience has shown can best be handled on a centralized basis. The handling of patent matters is one of these activities. The Patent Section, therefore, is organized as part of the Central Office Staff. Specifically, it is a part of the Engineering Staff and comes under the jurisdiction of the vice president-in-charge of the Engineering Staff.

The main office of the Patent Section is in Detroit. Other offices are maintained in Dayton, Ohio; Bristol, Connecticut; Washington, D.C.; and London, England. The activities of these offices are under the complete responsibility of and are coordinated by the director of the Patent Section (Fig. 1). The director, located in the Detroit office, is assisted by a corps of patent attorneys. Most of these patent attorneys are graduate engineers. With few exceptions, all are lawyers admitted to practice in one or more of several states.

Patent Section Has Varied Responsibilities

The Patent Section has responsibility for all patent, trade mark, copyright, and related matters affecting General Motors and its subsidiaries, both in the United States and foreign countries.

Some of the specific functions of the Patent Section are as follows:

- To obtain all patents on inventions and to register all trade marks and copyrights which are the property of GM
- To handle all charges of alleged infringement of patents, trade marks, and copyrights made by or against GM
- To handle all litigation based upon alleged infringement of patents, trade marks, copyrights, and other related matters in which GM is either the plaintiff or the defendant.
- To advise whether products, machines, processes, trade marks, or copyrights of GM infringe upon the rights of others or vice versa
- To negotiate and prepare all agreements relating to the sale or purchase of rights in and to patents, trade marks, copyrights, engineering information, and manufacturing know-how
- To assist in the negotiation, preparation, and interpretation of such parts of all other contracts, such as leases, purchase orders, and employe agreements, which deal with inventions, patents, trade marks, and copyrights.

Another function of the Patent Section is concerned with handling ideas submitted from outside of General Motors. All submissions of ideas and developments originating outside of GM are referred to the New Devices Section of the Engineering Staff. If it appears that a submission is of interest to GM the Patent Section then undertakes the responsibility, at the request of the New Devices Section, to investigate patent rights relating to the submission and to negotiate for the purchase of such rights.

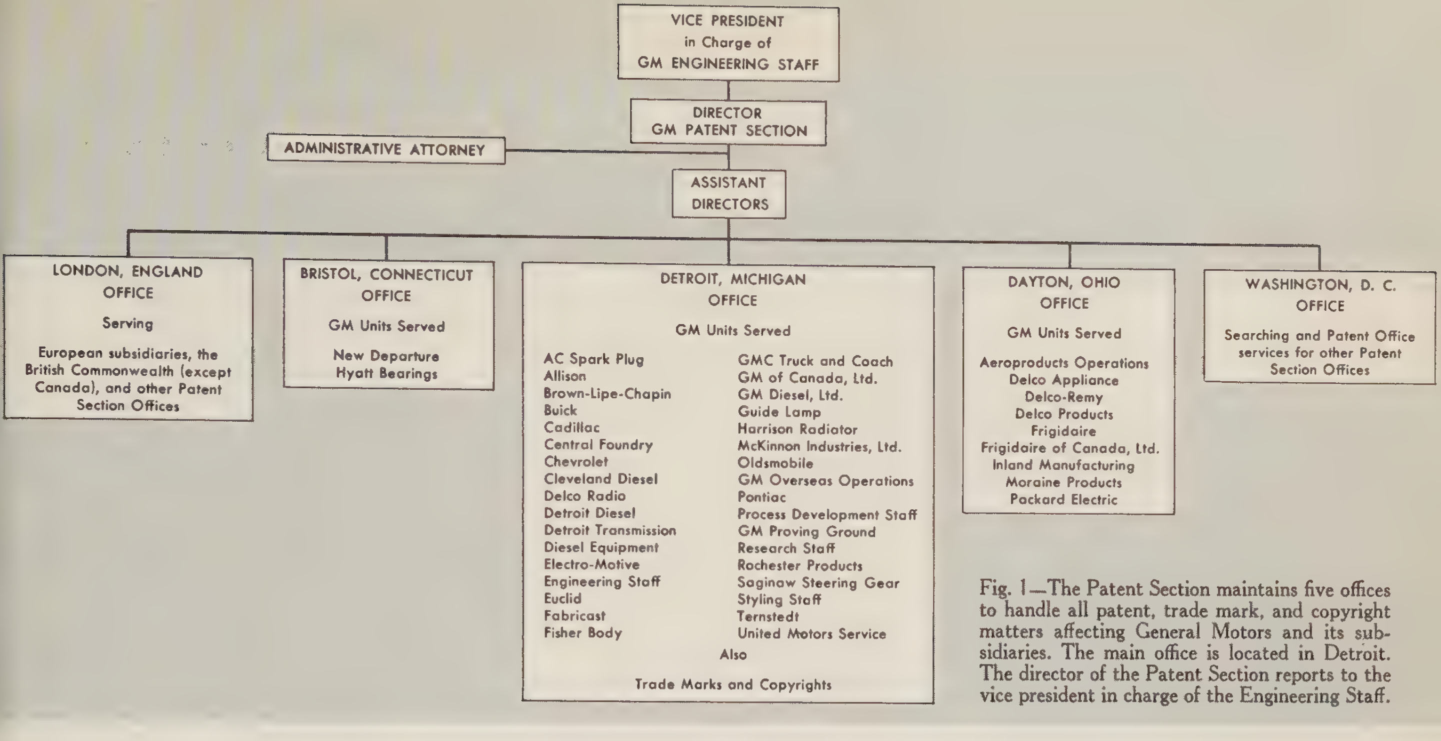


Fig. 1—The Patent Section maintains five offices to handle all patent, trade mark, and copyright matters affecting General Motors and its subsidiaries. The main office is located in Detroit. The director of the Patent Section reports to the vice president in charge of the Engineering Staff.

Patent Section Protects Divisional Interests

The principal reason for organizing the Patent Section as part of the Central Office Staff is the fact that patent matters usually affect more than one GM Division or operation. For example, a license granted under a patent taken out on behalf of one Division is binding on all other GM Divisions. Such a license may seem to be of little importance to the interested Division because of the limited nature of the patent involved. Conceivably, however, it could, if not properly worded, result in an implied license under a patent of much greater value to another Division.

As a second example, a license, taken out on behalf of one Division, is likewise binding upon all other Divisions. Such a license generally denies to the licensee the right to contest the validity of the patent. Accordingly, if the license is not properly worded by someone familiar with the facts GM-wide, it could be embarrassing not only to the interested Division but to other Divisions as well.

As a final example, it sometimes happens that two or more Divisions are engaged in somewhat similar research and developmental work, with each Division not informed fully of the other's work. In such a situation it is quite possible that an issued patent based on the work of one Division, if prosecuted at the Divisional level, could stand in the way of a much stronger patent based on the work of the other Division.

Patent Section Relies on Patent Contact Engineer

The fact that the Patent Section is a centralized operation means that it must rely largely on each Division and Staff for its information. To facilitate the submission of such information each Division and Staff has at least one patent contact engineer.

The patent contact engineer is responsible for informing the Patent Section of all research and developmental work in which his Division or Staff is engaged or plans to undertake and also of all proposed changes in its products, machines, and processes. It also is the responsibility of the patent contact engineer to refer promptly to the Patent Section such matters as: (a) proposed new trade marks, (b) notices, letters, or court papers relating to alleged infringement of patents, trade marks, and copyrights, (c) contracts, purchase orders, equipment leases, proposals, and so forth involving inventions, patents, technical information or know-how, trade marks, and copyrights, (d) publicity on new developments and manufacturing know-how, (e) proposals relating to the hiring of consultants or engineers known to have been engaged previously in the same field, and (f) all other analogous matters.

The necessity for the prompt submission of such information cannot be over emphasized. For example, assume that an engineer sketches a very meritorious invention but, for reasons beyond his control, cannot complete the invention by reducing it to practice. Such a sketch in the files of the engineer is of little if any value. On the other hand, his prompt submission to the Patent Section may result in the filing of an application for Letters Patent which, from a legal standpoint, is the full equivalent of an actual reduction to practice.

As another example, suppose an invention is about to be used in production or to be described in a publication. Failure to call such a matter to the attention of the Patent Section may result in the loss of patent rights in several foreign countries, where public use or publication anywhere in the world is a statutory bar to the grant of a patent.

Summary

General Motors engineers are engaged in a ceaseless effort to improve existing products, develop new products, and expand upon engineering and manufacturing know-how. Such dynamic activity requires the disposition of many patents and related matters which are best handled by the Patent Section on a centralized basis. To protect the interests of each Division and Staff, the Patent Section relies on the patent contact engineer to supply pertinent information on all matters for which the Patent Section is responsible.

Notes About Inventions and Inventors

Contributed by Patent Section Dayton Office Staff

THE following is a general listing of patents granted in the names of General Motors employes during the period August 1, 1957 to October 31, 1957.

AC Spark Plug Division
Flint, Michigan

- **Ralph O. Helgeby,** (*M.E. degree, Horton School of Technology, Norway, and General Motors Institute*) staff engineer, inventor in patent 2,802,442 for an in-line speedometer indicator.

- **Joseph N. Heller,** (*B.S.M.E. and B.S.E.E., Clemson College, 1928*) assistant staff engineer, and **Robert H. Spahr, Jr.,** no longer with GM, inventors in patent 2,804,161 for a multiple sound frequency inlet silencer.

- **Argyle G. Lautzenhiser,** (*B.S.E.E., Tri-State College, 1940*) senior project engineer, inventor in patent 2,806,918 for an electric switch.

- **Roy L. Bowers,** (*B.S., Michigan State University, 1930*) staff engineer, inventor in patent 2,808,139 for a windshield wiper actuating mechanism.

- **Wilfred A. Bychinsky,** (*B.S.E.E., 1930, M.S.E., 1931, and Ph.D., 1933, University of Michigan*) assistant chief engineer, Motor Group, inventor in patent 2,814,665 for a connector for an igniter plug.

- **Bertil H. Clason,** (*Coethen Polytekinikum, Germany, and Tekniska Skolan, Sweden*) senior project engineer, Automotive Engineering Department, inventor in patent 2,816,189 for a pressure actuated switch.

- **William E. Barnes,** (*B.M.E., Tri-State College, 1931 and Albion College*) experimental engineer, Experimental Engineering Department and **Gordon W. Harry,** (*B.S.M.E., University of Michigan, 1923*) staff engineer, Automotive Product Engineering Department, inventors in patent 2,818,027 for a fuel pump.

- **Joseph Zubaty,** (*M.S.M.E., University of Prague, 1918*) staff engineer—special assignment, Automotive Engineering Department, inventor in patent 2,812,753 for a rotary fuel distributor valve.

Allison Division
Indianapolis, Indiana

- **Otaker P. Prachar,** (*B.S.M.E., 1934 and M.S., 1936, University of Minnesota*) head, Research Group, inventor in patent 2,802,618 for a foreign object separator.

- **Charles J. McDowall,** (*B.S.M.E., University of Florida, 1927*) chief engineer, Advanced Design and Development Section, and **Arthur W. Gaubatz,** (*B.S., University of Wisconsin, 1920*) senior project engineer, Experimental Engineering Department, inventors in patent 2,804,241 for a flow control meter.

- **John B. Wheatley,** (*A.B.M.E., 1929, and M.E. in aeronautics, 1930, Stanford University*) assistant chief engineer, Advanced Design Engineering Department, inventor in patent 2,804,280 for a turbine bearing lubrication system.

- **Arthur W. Gaubatz*,** inventor in patents 2,804,526; 2,806,075; 2,808,007; and 2,811,871 for a control apparatus, a thermocouple, a gear pump or motor, and an adjustable cam respectively.

- **Donald G. Zimmerman,** (*B.S.M.E., Purdue University, 1940*) section chief on design projects, Power Turbine Engineering Department, inventor in patent 2,807,434 for a turbine rotor assembly.

- **Chester E. Hockert,** (*B.S.M.E., Armour Institute, 1937, and M.S.M.E., Cornell University, 1941*) chief engineer, Turbo-Jet Engineering Department, inventor in patent 2,807,436 for a turbine wheel and bucket assembly.

- **Arthur W. Gaubatz*, Otaker P. Prachar*, John B. Wheatley*,** and **Donald G. Zimmerman*,** inventors in patent 2,809,503 for a gas turbine shaft.

- **Robert P. Atkinson,** (*B.S.M.E., Purdue University, 1935*) section chief, Advance Design and Development Department, inventor in patent 2,812,196 for a piston ring turbine shaft seal.

- **Wilgus S. Broffitt,** (*B.S.M.E., University of Kentucky, 1938*) head, Design Group, inventor in patents 2,811,833 and 2,817,490 for turbine cooling and a turbine bucket with internal fins, respectively.

Aeroproducts Operations
Allison Division
Dayton, Ohio

- **Howard M. Geyer,** (*B.S.I.E., University of Alabama, 1940*) chief research engineer, inventor in patent 2,801,615 for an actuator with multiple disc type locking means, in patent 2,801,616 for a multiple position actuator, in patent 2,802,454 for a dual actuator, in patents 2,804,053 and 2,804,054 for an actuator and locking means therefor, in patent 2,806,383 for an actuator assembly, in patent 2,806,450 for hydraulic actuators, and in patent 2,815,005 for a fluid pressure actuator with stroke end locking.

- **Kenneth L. Berninger,** (*Purdue University*) senior project engineer, **William A. Weis,** (*B.M.E., University of Dayton, 1938*) senior designer, **Garthwood R. Taylor,** (*B.S.M.E., Detroit Institute of Technology, 1941*) section head, **Robert C. Treseder,** no longer with GM, and **Albert P. Dinsmore,** no longer with GM, inventors in patent 2,804,154 for a con-current blade pitch control of coaxial propellers.

- **Howard M. Geyer*** and **Frederick L. Ruhl,** (*B.E.E., The Ohio State University,* *1940*) project engineer, accessory design, inventors in patent 2,810,256 for an actuator with electric motor drive and means for controlling the degree of motor energization.

- **Roy C. Bodem,** (*University of Dayton*) designer, Engineering Department, and **James W. Light,** (*Miami University and The Ohio State University*) experimental engineer, Engineering Department, inventors in patent 2,811,951 for an actuator and locking means therefor.

- **Maxwell A. Dicken,** draftsman, Engineering Department, and **Paul T. Keim,** not with GM, inventors in patent 2,817,319 for a windshield wiper motor.

Brown-Lipe-Chapin Division
Syracuse, New York

- **Stanford Landell,** (*University of Pennsylvania*) works manager, inventor in patents 2,804,346 and 2,815,986. Both patents are for a wheel cover.

Buick Motor Division
Flint, Michigan

- **John A. Stallings,** (*B.S.M.E., Michigan State University, 1949*) senior contact engineer, inventor in patent 2,804,324 for a seal.

- **William F. Williams,** (*B.I.E., General Motors Institute, 1947*) assistant welding engineer, Metallurgical Department, inventor in patent 2,806,168 for a welding control system.

- **Henry W. Boylan,** (*Wayne State University, 1929*) staff engineer, heating and cooling, inventor in patent 2,809,620 for an ignition apparatus.

Cadillac Motor Car Division
Detroit, Michigan

- **Webster J. Owen,** (*B.S., Beloit College, 1936*) assistant staff engineer, inventor in patent 2,807,153 for a vehicle refrigerating apparatus.

- **Daniel M. Adams,** (*Detroit Institute of Technology and University of Michigan*) staff engineer, Body and Sheet Metal Section, inventor in patent 2,807,899 for a license plate display device.

- **Lawrence C. Gladen,** now with Euclid Division, inventor in patent 2,806,126 for an arc welding apparatus.

***Inventors' names marked with an asterisk have biographical listings noted previously in this issue's Notes About Inventions and Inventors.**

- **John T. Hoban,** (*B.M.E., University of Dayton, 1943*) assistant staff engineer, Chassis Department, inventor in patent 2,817,510 for a rebound bumper.

- **Robert T. Doughty,** (*B.M.E., Tri-State College, 1943*) senior project engineer, Engine Cooling, Fuel, and Exhaust Department, inventor in patent 2,818,131 for a muffler.

Chevrolet Motor Division
Detroit, Michigan

- **Edmond E. Madison,** (*Wayne State University and Lawrence Institute of Technology*) assistant staff engineer, Accessory Department, inventor in patent 2,802,395 for a mirror support structure.

- **Eugene B. Etchells,** (*B.S.E.E., University of Michigan, 1932*) assistant staff engineer, Engine Design Group, inventor in patent 2,807,253 for a poppet valve guide and in patent 2,811,959 for a valve actuating mechanism.

- **Robert W. Graham,** (*B.S.M.E., University of Michigan, 1949*) senior project engineer, Passenger Car Chassis Section, inventor in patent 2,818,051 for a rotating device.

- **Adelbert E. Kolbe,** (*University of Michigan*) assistant staff engineer-in-charge of advanced engine design, Research and Development Department, and **Everett B. Sherrick,** (*Wayne State University, Purdue University*) section engineer, Power Development Section, GM Engineering Staff, inventors in patent 2,815,682 for a crankshaft.

- **Donald F. Urban,** (*Wayne State University*) design engineer, Passenger Car Group, and **Arnold J. Maletzke,** now with Brown-Lipe-Chapin Division, inventors in patent 2,812,955 for a combined hinge closure and lamp mounting.

- **Loren R. Papenguth,** (*B.S.M.E., University of Michigan, 1948*) senior project engineer, Engine Design Group, inventor in patent 2,818,050 for a lubricating system.

Delco Products Division
Dayton, Ohio

- **George W. Jackson,** (*B.S.M.E., Purdue University, 1937*) staff engineer, automotive and mechanical products, inventor in patent 2,802,664 for a hydro-pneumatic suspension unit, in patent 2,802,674 for a roll control system for a motor vehicle, in patent 2,807,146 for a vehicle refrigerating apparatus, and in patent 2,809,051 for a vehicle suspension having fluid pressure height control.

Delco-Remy Division
Anderson, Indiana

- **Harold V. Elliott,** (*General Motors Institute*) senior project engineer, and **William E. Brown,** (*General Motors Institute*) staff engineer, inventors in patents 2,804,512 and 2,807,680 for an electric switch and a control device, respectively.

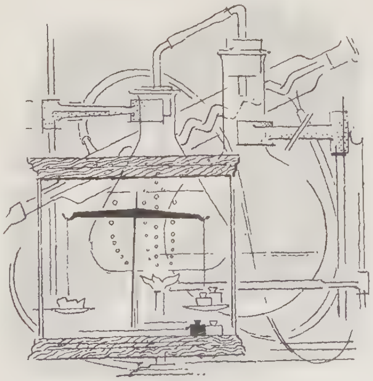
- **David C. Redick** (*General Motors Institute*) section head, switches and horns, inventor in patent 2,807,729 for a control circuit for an engine starting and ignition system.

- **Lyman A. Rice,** (*B.S.E.E., University of Utah, 1935, and M.S.E., University of Michigan, 1936*) staff engineer, inventor in patents 2,807,869 and 2,811,677 for a method of winding a wire coil and a regulator, respectively.

- **Harold V. Elliott***, inventor in patent 2,808,476 for an electric switch.

- **Harold J. Cromwell,** (*B.S.M.E., Purdue University, 1933*) senior research engineer, inventor in patent 2,808,815 for a windshield wiper motor.

- **Brooks H. Short,** (*B.S.E.E., 1931 and*



M.S.E.E., 1934, Purdue University) supervisor, engineering research, inventor in patent 2,809,301 for a vehicle electrical system.

- **James C. Norris,** (*Purdue University*) head, Ignition Section, inventor in patent 2,809,619 for a distributor.

- **William E. Brown*,** and **Harold V. Elliott*,** inventors in patent 2,810,794 for a headlight control switch.

- **William E. Brown*,** inventor in patent 2,811,598 for a starter switch.

Detroit Diesel Engine Division
Detroit, Michigan

- **John S. Hanson,** (*B.S.M.E., University of Wisconsin, 1950*) experimental metallurgist; **Jack E. LaBelle,** (*B.S.Ch.E., Michigan State University, 1937*) chief metallurgist, Metallurgical Department; and **Gilbert M. Lahr,** (*B.I.E., General Motors Institute, 1948*) general supervisor, laboratory, inventors in patent 2,818,359 for a method of making flanged cylinder liners.

Detroit Transmission Division
Ypsilanti, Michigan

- **Walter B. Herndon,** (*B.S.E., State College of Washington, 1928, and M.S.E., University of Michigan, 1930*) director of engineering and sales, and **Richard L. Thorman,** (*General Motors Institute, 1935*) senior project engineer, inventors in patent 2,805,628 for a variable capacity pump.

- **John J. O'Malley,** (*Wayne State University*) assistant staff engineer, inventor in patent 2,809,536 for accumulator controls for automatic transmissions.

Diesel Equipment Division
Grand Rapids, Michigan

- **William A. Fletcher,** (*General Motors Institute, 1930*) director, Manufacturing Facilities and Services Department, and **Max E. Todd,** (*University of Cincinnati*) senior engineer, Delco-Remy Division, inventors in patent 2,811,058 for a workpiece handling device.

Electro-Motive Division
La Grange, Illinois

- **Kenneth D. Swander, Jr.,** (*B.S.M.E., Purdue University, 1942*) assistant air brake engineer, and **Frank J. Vegh,** no longer with GM, inventors in patent 2,802,935 for a circuit checker for a vehicle electro-pneumatic brake system.

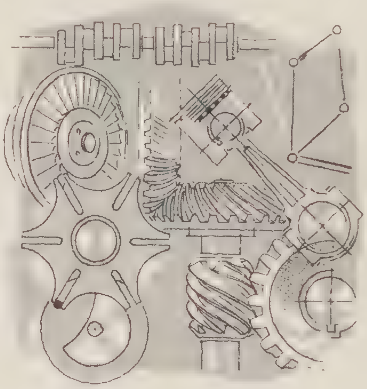
- **Wallace A. Christianson,** (*B.S.M.E., University of North Dakota, 1943*) senior project engineer, Research Department, inventor in patent 2,803,199 for a railway vehicle steering means.

- **Bert H. Hefner,** electrical engineer, inventor in patent 2,803,696 for an insulating seal.

- **Elmer E. Thiessen,** (*B.S.E.E., Iowa State College, 1940*) a-c electrical design engineer, inventor in patent 2,804,404 for a method of impregnating electrical windings.

- **Torsten O. Lillquist,** electrical research engineer, inventor in patent 2,806,149 for a wheel slip control system.

- **Albert N. Addie,** (*B.S.M.E., Illinois Institute of Technology, 1944, and M.S.M.E., Case Institute of Technology, 1947*) chief research engineer, Research Department, inventor in patent 2,807,135 for a free piston power plant with afterburner.



GM Engineering Staff
Detroit, Michigan

- **Lewis D. Burch,** (*B.S.M.E., Purdue University, 1923, George Washington University, Akron Law School, and Wayne State University*) patent attorney, Central Office Patent Section, inventor in patent 2,802,237 for piston structure and combustion chamber, in patent 2,810,378 for cylinder block and method of making the same, and in patent 2,815,924 for butterfly valve structures.

- **Oliver K. Kelley,** (*B.S., Chicago Technical College, 1925 and Massachusetts Institute of Technology*) now chief engineer, Buick Motor Division, inventor in patents 2,803,974 and 2,814,214 for a four phase converter drive and a transmission, respectively.

- **Warren E. Finken,** (*B.S.M.E. University of Wisconsin, 1948; LL.B., George Washington University, 1951*) patent attorney, Dayton Office, Patent Section, inventor in patent 2,806,557 for a windshield wiper transmission assembly and weather shield therefor.

- **Donald C. Unger,** (*Detroit Institute of Technology and University of Michigan*) project engineer, Power Development Section, inventor in patent 2,807,245 for a water heated intake manifold and control system therefor.

- **Lothrop M. Forbush,** (*B. S., Harvard University, 1939 and Massachusetts Institute of Technology*) assistant engineer-in-charge, Automotive Ordnance Section and **Roland V. Hutchinson,** (*Municipal Technical School, Manchester, England*) now on special assignment work for Engineering Staff, inventors in patent 2,809,869 for a vehicle wheel.

- **George P. Ransom,** (*B.S.M.E., University of Michigan, 1949*) section engineer, Power Development Section, inventor in patent 2,810,462 for a self-actuating clutch mechanism.

- **Charles N. McCarthy,** (*International School of Correspondence, 1928*) chassis engineer, Passenger Car Development, inventor in patent 2,811,865 for a transmission control.

- **Oliver K. Kelley*** and **Gilbert K. Hause,** engineer-in-charge, Transmission Development Group, inventors in patent 2,816,630 for a front wheel mounting for a disk brake.

- **Edwin S. Dybvig,** (*B.S.E.E., University of Minnesota, 1929 and LL.B., Washington College of Law, 1933*) patent attorney, Patent Section, Dayton Office, inventor in patent 2,817,124 for a refrigeration apparatus.

- **Eugene W. Christen,** (*B.S.M.E., Purdue University, 1948 and LL.B., Georgetown University, 1951*) patent attorney, Patent

These patent listings are informative only and are not intended to define the coverage which is determined by the claims of each one.

Section, Central Office, inventor in patent 2,817,512 for a window regulator safety device.

Euclid Division
Cleveland, Ohio

- **Arthur P. Armington,** (*B.S.M.E., Case Institute of Technology*) supervisor, Sales Development Office, inventor in patent 2,801,702 for a steerable driving axle.

Fisher Body Division
Detroit, Michigan

- **Clyde H. Schamel,** (*B.S.E.E., University of Notre Dame, 1927*) engineer-in-charge, Central Experimental and Development Department, and **Claud S. Semar,** (*Detroit City College, University of Michigan, and Wayne State University*) senior project engineer, Experimental and Development Department, inventors in patents 2,803,290 and 2,812,538 for a seat mechanism and a hinge check and hold-open, respectively.

- **Claud S. Semar*** inventor in patent 2,805,886 for a folding pillar and vertically movable window arrangement for vehicle bodies, and in patent 2,810,153 for a torque rod door counterbalance.

- **Napoleon P. Boretti,** (*B.E.E., University of Detroit, 1935*) assistant engineer-in-charge, Process Development Department, inventor in patent 2,810,431 for a seat spring attachment.

- **George D. Legge,** (*Western Technical Institute, Toronto, Canada*) group leader—hardware design, Trim and Hardware Styling Department, inventor in patent 2,812,097 for an ash tray.

- **Arkady A. Lobanoff,** (*Wayne State University and University of Michigan*) engineer-in-charge, front end and instrument panels, Design and Drafting Department, inventor in patents 2,812,558 and 2,815,796 for a windshield mounting channel and a tilting seat back lock, respectively.

- **John E. Tessmar,** senior project engineer, Trim Engineering Department, and **Leo E. Seymour,** (*Valparaiso University and George Thompson School of Engineering*) Trim Engineering representative at Fisher Body—Livonia plant, inventors in patent 2,815,979 for a means for attaching headlining wires.

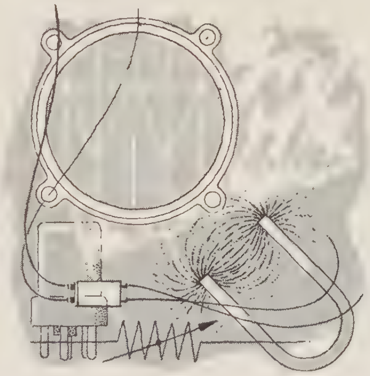
Frigidaire Division
Dayton, Ohio

- **Richard S. Gaugler,** (*B.S.Ch.E., Purdue University, 1922*) supervisor of major product line, and **Robert Galin,** (*B.S.M.E., Robert College, Istanbul, Turkey, 1947, and M.S.M.E., University of Michigan, 1949*) senior project engineer, Research and Future Products Engineering Department, inventors in patent 2,801,527 for an ice making apparatus.

- **Byron L. Brucken,** (*B.S., University of Dayton, 1956*) senior project engineer, Research and Future Products Department, inventor in patent 2,801,549 for a rotation and reciprocation power unit.

- **Edward C. Simmons,** (*University of Dayton*) senior engineer, Refrigerated Appliances Engineering Department, inventor in patent 2,802,346 for a refrigerator evaporator with defroster-heater.

- **Joseph R. Pichler,** (*B.I.E., The Ohio State University, 1934*) section head, Refrigerated Appliances Engineering Department, inventor in patent 2,806,357 for an ice maker.



- **James W. Jacobs,** (*B.S.M.E., University of Dayton, 1954*) section engineer, Non-Refrigerated Appliances Engineering Department, inventor in patents 2,806,358 and 2,807,147 for a vehicle refrigerating apparatus; in patent 2,807,148 for a refrigerating apparatus; in patent 2,807,172 for a variable speed transmission; in patent 2,807,246 for engine fan control; in patent 2,807,344 for a clutch for refrigerating apparatus; in patent 2,812,642 for a refrigerating apparatus; and in patent 2,817,123 for a refrigerating apparatus.

- **Victor A. Williamitis,** (*B. Chem. E., University of Dayton, 1938*) senior experimental chemist, Materials and Process Engineering Department, inventor in patent 2,807,155 for working fluids in refrigeration apparatus.

- **Keith K. Kesling,** (*University of Dayton and Dayton Art Institute*) project and design engineer, Research and Future Products Engineering Department, inventor in patent 2,807,837 for a refrigerating cabinet door.

- **Shirley F. Ehman,** (*B.S.M.E., University of Illinois, 1931*) senior project engineer, Research and Future Products Engineering Department, inventor in patent 2,807,992 for an air distributor for air conditioning units.

- **Keith K. Kesling*** and **James W. Jacobs,*** inventors in patent 2,808,497 for a domestic appliance.

- **Harry F. Clark,** (*E. E., University of Cincinnati, 1921*) senior project engineer, Refrigerated Appliances Engineering Department, inventor in patent 2,808,553 for a starting control for split-phase motors.

- **Verlos G. Sharpe,** (*B.S.M.E., Purdue University, 1948*) section engineer, Refrigerated Appliances Engineering Department, inventor in patent 2,808,708 for an ice block ejecting device.

- **George W. Schauer, Jr.,** project engineer, Non-Refrigerated Appliances Engineering Department, inventor in patent 2,809,267 for a domestic appliance.

- **Clifford H. Wurtz,** (*B.S., University of Illinois, 1929*) supervisor of major product line, Refrigerated Appliances Engineering Department, and **Harvey R. Tuck,** senior project engineer, Research and Future Product Engineering Department, inventors in patent 2,810,266 for a refrigerator cabinet structure.

- **Orson V. Saunders,** supervisor of major product line, Refrigerated Appliances Engineering Department, **Verlos G. Sharpe***, and **John M. Murphy,** (*B.S.E.E., Purdue University, 1930*) section engineer, Refrigerated Appliances Engineering Department, inventors in patent 2,810,271 for refrigerating apparatus.

- **Millard E. Fry,** (*B.S.M.E., University of Pittsburgh, 1931*) senior project engineer, Non-Refrigerated Appliances Engineering Department, inventor in patents 2,811,627 and 2,816,999. Both patents are for a domestic appliance.

- **George C. Pearce,** (*B.S.M.E., Stanford University, 1924*) section head, Non-refrigerated Appliances Engineering Department, inventor in patent 2,815,428 for a domestic appliance.

- **Everett C. Hutchins,** (*Eastern State College*) foreman—welding machine repair, Maintenance Department, inventor in patent 2,816,211 for a refrigerating apparatus.

- **Millard E. Fry*** and **Francis H. McCormick,** retired, inventors in patent 2,816,998 for a domestic appliance.

GM of Canada, Ltd.

Oshawa, Ontario, Canada

- **James H. Halliday,** (*B.S., Queens University, 1923*) plant engineer, inventor in patent 2,810,457 for a lubricator.

GM Overseas Operations Division

New York, New York

- **Harry R. Stocks,** assistant chief engineer, Vauxhall Motors, Ltd., Luton, England, inventor in patent 2,802,692 for a vehicle ventilator.

- **Friedrich Glaeser,** (*Engineer degree, Rheinische Ingenieurschule Bingen Polytechnikam Friedberg, 1923*) senior designer and group leader, Engineering Department—Body Drafting, Adam Opel, Russelsheim/Main, Germany, inventor in patent 2,793,906 for a spring-hinged ventilating side window for automobiles.

GMC Truck and Coach Division

Pontiac, Michigan

- **Glen E. Brookbank,** foreman in the Engineering Department, inventor in patent 2,802,540 for a load support mounted for retraction.

- **Hans O. Schjolin,** (*B.S. degree, Karlstad College, Sweden, 1920, and Polytechnical Institute, Mittweida, Germany, 1923*) new development engineer, Engineering Department, inventor in patent 2,810,269 for a vehicle refrigerating apparatus.

Guide Lamp Division

Anderson, Indiana

- **Robert N. Falge,** retired, and **Charles W. Miller,** (*Purdue University*) project engineer, inventors in patent 2,806,180 for an override control for automatic headlight dimmer.

- **Howard C. Mead,** (*Western Reserve University*) chief engineer, and **Robert C. Miller,** (*Indiana Technical College, 1935*) assistant plant engineer, inventors in patent 2,809,399 for a method of uniting metal to plastic.

- **Howard I. Slone,** (*B.S.E.E., Purdue University, 1938*) accessory engineer, **David P. Clayton,** junior designer, and **Edward L. Barcus,** senior designer—drafting, inventors in patent 2,811,592 for electric switches.

- **James J. Martin,** drafting group supervisor, inventor in patent 2,814,720 for a vehicle lamp.

- **John H. Diedring,** (*Fenn College*) engineering head, original equipment lamps, inventor in patent 2,814,722 for a resilient lamp mounting.

Harrison Radiator Division

Lockport, New York

- **Charles J. O'Brien,** (*B.S.M.E., Clarkson College of Technology, 1927*) senior engineer, inventor in patent 2,808,254 for a hot gas gun.

Inland Manufacturing Division

Dayton, Ohio

- **Arthur J. Frei,** senior project engineer, inventor in patents 2,809,499 and 2,809,500 for an ice block ejecting device and an ice block releasing device, respectively.

- **Thomas O. Mathues,** (*B.M.E., General Motors Institute, 1947*) chief engineer, inventor in patent 2,810,301 for a steering wheel and method of making same.

Moraine Products Division

Dayton, Ohio

- **James O. Helvern,** (*B.A., Wittenburg College, 1927*) senior designer, inventor in patent 2,804,177 for an automatic brake wear adjuster for vehicles.

- **Harold W. Schultz,** section engineer, inventor in patent 2,809,422 for a method of making a composite article.

- **Edward J. Vosler,** superintendent, processing and plant layout, and **Rodger F. Marsh,** no longer with GM, inventors in patent 2,811,057 for a punch press and method of operation.

Packard Electric Division

Warren, Ohio

- **Robert E. Kirk,** (*Case Institute of Technology*) product designer, Assembly Components Design Section, inventor in patent 2,802,194 for a terminal.

- **Robert C. Woofter,** (*Fenn College*) chief, Assembly Components Design Section, **Robert E. Kirk*** and **Robert H. Sims,** (*Illinois Institute of Technology*) customer contact engineer, inventors in patent 2,809,361 for a multiple wire connector.

Pontiac Motor Division

Pontiac, Michigan

- **William J. DeBeaubien,** (*General Motors Institute, 1932*) heating, ventilating, and air conditioning engineer, **Herman S. Kaiser,** body engineer, and **John R. Holmes,** retired, inventors in patent 2,810,270 for air conditioning systems for vehicles.

GM Process Development Staff

Detroit, Michigan

- **Ward F. Diehl,** (*B.M.E., General Motors Institute, 1949*) senior project engineer, and **Richard D. Purcell,** now project engineer, Vauxhall Motors, Ltd., Luton, England, inventors in patent 2,803,093 for a horizontal gyrofinishing machine and method.

- **George R. Squibb,** (*B.S.M.E., and B.S.A.E., University of Michigan, 1933*) chief project engineer, and **Donald A. Urquhart,** no longer with GM, inventors in patent 2,802,509 for a process and apparatus for grinding piston rings and product thereof.

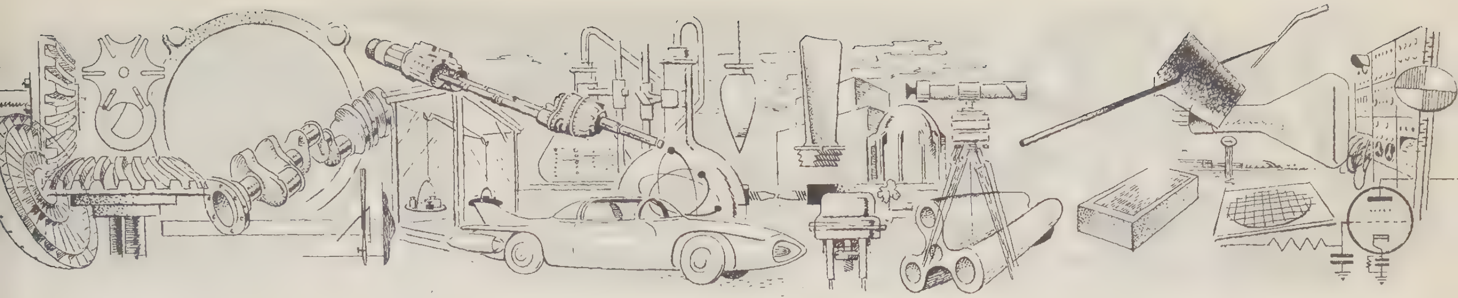
GM Research Staff

Detroit, Michigan

- **Wardley D. McMaster,** assistant head, Chemistry Department, inventor in patent 2,805,844 for a spray booth.

- **James D. Fleming,** (*B.S.M.E., Texas Technological College, 1947; M.S., 1948 and Ph.D., 1950, University of Wisconsin*) senior research engineer, Mechanical Development Department, inventor in patent 2,807,511 for a coated piston ring.

- **Alfred W. Schlucter,** (*B.S.Chem.E., 1919, M.S.Chem.E., 1921, Ph.D., 1926, Uni-*



versity of Michigan) research engineer, Mechanical Development Department, inventor in patent 2,807,540 for an aluminum base bearing.

- **Robert F. Thomson,** (*B.S.M.E., 1937, M.S.M.E., 1940, and Ph. D., 1941, University of Michigan*) head, Metallurgical Engineering Department, and **Fred W. Webbere,** (*B.S., University of Wisconsin, 1941*) supervisor, Metallurgy Department, inventors in patent 2,809,407 for a method of making a composite metal article.

- **Dean K. Hanink,** (*B.S.Met.E., University of Michigan, 1942*) now chief metallurgist, Metallurgical Department, Allison Division, inventor in patent 2,809,423 for a salt flux and method for brazing aluminum parts therewith.

- **William A. Turunen,** (*B.S.M.E., Michigan College of Mining and Technology, 1939, and M.S. degree, Columbia University, 1946*) head, Gas Turbines Department, **Patrick W. O'Connell,** deceased, and **DeOwen Nichols,** no longer with GM, inventors in patent 2,812,157 for a turbine blade cooling system.

- **Arnold DeHart,** (*B.S.M.E., West Virginia University, 1950*) senior research engineer, Mechanical Development Department, and **James D. Fleming***, inventors in patent 2,817,562 for a coated piston.

- **Robert M. Van House,** (*B.S.M.E., University of Michigan, 1939*) supervisor, chassis design, Engineering Mechanics Department, inventor in patent 2,814,481 for a laminated spring.

- **William R. Vincent,** (*B.S. in Chemistry, Eastern Michigan College, 1941*) research chemist, Electrochemistry Department, and **Elmer R. Breining,** no longer with GM, inventors in patent 2,817,628 for an antimony plating bath.

Rochester Products Division
Rochester, New York

- **Joseph M. McDonnell,** (*Newark College of Engineering*) senior engineer, and **Henry D. Mowers,** production engineer, inventors in patent 2,802,458 for a fluid motor.

- **Elmer Olson,** (*Lewis Institute*) inventor in patent 2,804,087 for a carburetor fuel valve actuating mechanism.

- **Lawrence C. Dermond,** (*Purdue University and Tri-State College*) staff engineer, inventor in patent 2,808,244 for a carburetor.

- **Elmer Olson*** and **Arthur W. Winter,** (*University of Detroit*) staff engineer—laboratory and road testing, inventors in patent 2,810,560 for a carburetor.

Saginaw Steering Gear Division
Saginaw, Michigan

- **Arthur F. Bohnhoff,** (*B.S.M.E., Michigan College of Mining and Technology, 1938*) senior designer, and **Paul V. Wysong, Jr.,** (*University of Kansas*) sales supervisor, actuators, inventors in patent 2,802,354 for a coupling.

- **C. W. Lincoln,** retired, **Ralph A. Malone,** deceased, and **Paul V. Wysong, Jr.***, inventors in patent 2,802,371 for a mechanical follow-up mechanism.

GM Styling Staff
Detroit, Michigan

- **Harold E. Van Voorhees,** (*B.S.M.E., Purdue University, 1915*) now senior design engineer, New Product Development Department, Ternstedt Division, and **Frederick C. Walther,** retired, inventor in patent 2,809,690 for a pivoted seat

- **William H. Daniels,** senior project engineer, Interior Engineering Department, inventor in patent 2,809,862 for a control means for operation of a roof-closure in response to movements of the door and seat.

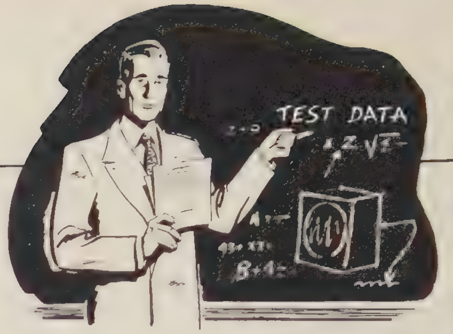
Ternstedt Division
Detroit, Michigan

- **LaVerne B. Ragsdale,** (*University of Detroit, Franklin College, and B.S.M.E., Lawrence Institute of Technology, 1939*) staff engineer, Product Development Department, inventor in patent 2,799,889 for a hinge hold-open; in patent 2,799,891 for a deck lid counter-balance and hold-open; in patent 2,805,442 for a lid hinge and hold-open; in patent 2,808,280 for a closure latch; in patent 2,812,535 for a hinge hold-open; and in patent 2,812,536 for a hinge and ball hold-open.

- **C. Derwood Tuttle,** (*Ph.D., Michigan State University, 1933*) senior experimental chemist, metallurgist, physicist, Process Development Department and **Grayland T. Larsen,** ((*B.S. Chem. E., Michigan College of Mining and Technology, 1937*) general supervisor, Process Engineering Department, inventors in patent 2,805,642 for an electrostatic spray painting apparatus.

- **Louis P. Garvey,** (*B.M.E., University of Detroit, 1939*) and **Claud S. Semar,** (*Detroit City College, University of Michigan, and Wayne State University*) now senior project engineers, Experimental and Development Department, Fisher Body Division, and **Akera Tanaka,** (*B.S.M.E., Michigan State University, 1949*) group leader, design, Product Development Department, inventors in patent 2,809,689 for a seat adjuster.

Technical Presentations by GM Engineers



The technical presentation is another way in which information about current engineering and scientific developments in General Motors can be made available to the public. A listing of speaking appearances by General Motors engineers, such as that given below, usually includes the presentation of papers before professional societies, lecturing to college engineering classes or student societies, and speaking to civic or governmental organizations. Educators who wish assistance in obtaining the services of GM engineers to speak to student groups may write to the Educational Relations Section, Public Relations Staff, General Motors Technical Center, P. O. Box 177, North End Station, Detroit 2, Michigan.

GM personnel who have made recent presentations are as follows:

Automotive Engineering

Roderick G. Tipping, assistant staff engineer, Product Engineering Department, Detroit Transmission Division, before the OTAC, Military and Pacific Car and Foundry, Renton, Washington, November 7; title: Military Transmission, Model 198-M.

Alex C. Mair, staff engineer, Truck Chassis Department, Chevrolet Motor Division, before the Detroit section, Society of Automotive Engineers, November 18; title: Road Behavior of a Modern Truck.

Before the Detroit junior section, S.A.E., November 25; **Hulki Aldikacti**, project engineer, Product Engineering Department, Pontiac Motor Division, title: Ever-Level Air Ride; and **E. W. Anderson**, research engineer, Vehicle Test Section, Cadillac Motor Car Division, title: 1958 Cadillac Air Suspension.

George W. Jackson, staff engineer, Automotive and Mechanical Products Department, Delco Products Division, before the Dayton, Ohio, section, S.A.E., December 10, and before the Pennsylvania State University student section, S.A.E., December 12; title: General Motors Air Suspension.

Dr. Ledra M. Lawton, chief chemist, Product Engineering Department, Harrison Radiator Division, before the Chemical Specialty Manufacturers Association, Hollywood, California, December 10; title: Helpful Remarks to Manufacturers of Cleaners, Sealers, and Inhibitors for Automotive Cooling Systems.

John F. Pribonic, section engineer, Advance Automotive Design Department, Delco Products Division, before Wittenburg College students, Dayton, Ohio, December 13, 1957; title: General Motors Air Suspension.

George W. Jackson, Charles L. Richter, sales manager, Automotive Sales Department, and **Pat H. Irelan**, Advertising Department, Delco Products Division, over station WHIO—TV, Dayton, Ohio, December 26, 1957; title: panel discussion on Delco Products and its part in the development and production of the General Motors Air Suspension.

John G. Locklin, engineer on structures and dynamics, Advanced Design Department, GMC Truck and Coach Division, before the Cincinnati, Ohio, section, S.A.E., November 25; title: Air Suspension on Highway Tractors, and before the Baltimore, Maryland, section, S.A.E., January 9; title: Air Suspension Development.

Before the S.A.E. Annual Winter Meeting, Detroit, January 13-17; **Kai H. Hansen**, staff engineer, **J. T. Bertsch**, research engineer, and **R. E. Denzer**, senior research engineer, Research and Development Department, Chevrolet Motor Division, title: The Chevrolet Level Air Suspension; **Harold T. Johnson**, manager, Manufacturing Staff, GM Overseas Operations Division, title: Recent Progress in European Automotive Industry; **Ralph W. Perkins**, product engineer, Product Engineering Department, Oldsmobile Division, title: Oldsmobile's New-Matic Ride; **J. T. Wentworth**, senior research engineer, Fuels and Lubricants Department, GM Research Staff, title: Carburetor Evaporation Losses; **Forest R. McFarland**, assistant chief engineer, Buick Motor Division, title: The Air-Poise Suspension—Buick's Solution to the Air Ride Problem. Mr. McFarland also appeared before the Metropolitan section, S.A.E., New York City, January 9; title: Automatic Transmissions and Torque Converters.

Harold Drew, chief engineer, GM Overseas Operations Division, before the S.A.E. Panel Session, Detroit, January 27; title: Small Cars.

Kenneth B. Valentine, metallurgical engineer, Product Engineering Department, Pontiac Motor Division, before the S.A.E. Fuel and Lubricant Symposium, Los Angeles, January 28; title: Some Experiences with Throttle Body Deposits.

Donald Stoltman, senior project engineer, Product Engineering and Development Department, Rochester Products Division, before the Government Working Conference, N.A.D.A. Convention, Miami, January 14; title: Fuel Injection.

Edward Gray, assistant chief engineer, Production Engineering, Chevrolet Motor Division, before the Metropolitan section, S.A.E., New York City, February 11; title: Field Testing.

Donald J. La Belle, staff engineer, Truck Engineering Department, GMC Truck and Coach Division, before the Detroit Rubber and Plastics Group, February 7; title: Future of Air Suspension Commercial Vehicles, and before the California Trucking Association, Los Angeles, February 11; title: Air Suspension for Commercial Vehicles.

S. L. Milliken, future development supervisor, Engineering Department, Cadillac Motor Car Division, before the Cleveland, Ohio, section, S.A.E., December 9; title: The Cadillac Air Suspension for 1958, and before the Dallas, Texas, section, S.A.E., February 14; title: Air Suspensions in 1958 Automobiles.

Bearings and Lubrication

Robert F. Guy, lubrication engineer, Master Mechanics Department, Detroit Transmission Division, before the Detroit section, American Society of Lubrication Engineers, September 23; title: An Effective Lubrication Program and its Value in Preventative Maintenance.

T. W. Bakewell, supervisor, general machine tool applications, Product Engineering Department, New Departure Division, before the A.S.L.E., Boston, November 18; title: Ball Bearing Lubrication, and before the S.A.E. Annual Winter Meeting, Detroit, January 16; title: Mechanical Factors Involved in Bearing Design for Aircraft Electric Motors.

C. E. Norton, chief metallurgist, Product Engineering Department, New Departure Division, before the Detroit section, S.A.E., December 5; title: Metallurgical Aspects of High Quality Bearings, and before personnel of Convair Division, General Dynamics Corporation, Fort Worth, Texas, December 12; title: Metallurgy of High Temperature Bearings.

C. R. Gillette, chief chemist, Product Engineering Department, New Departure Division, before personnel of Convair Division, General Dynamics Corporation, Fort Worth, Texas, December 12; title: Ball Bearing Lubricants at High Temperatures, and before the Connecticut chapter, A.S.L.E., Hartford, December 22; title: Lubrication of Anti-Friction Ball Bearings.

M. E. Otterbein, manager, Research and Development, Hyatt Bearings Division, before the Dayton, Ohio, section, A.S.L.E., January 28; title: Aircraft Gas Turbine Oils and Bearing Fatigue Life.

Engineering Career Guidance

R. D. Tyler, superintendent, electronic development, Electronics and Parts Test Department, Allison Division, before the Indiana Association for Supervision and Curriculum Development, Turkey Run State Park, October 12; title: Opportunities in Engineering and Science.

Merton Jacobs, instructor, Electronics Section, Science Department, General Motors Institute, before the American Institute of Electrical Engineers, Chicago, November 14; title: Training for the Industrial Technician.

R. A. Fournier, physical test laboratory, Product Engineering Department, New Departure Division, before students of Bristol High School, Bristol, Connecticut, November 15; title: Laboratory Technicians.

William K. Steinhagen, assistant engineer-in-charge, Power Development Group, GM Engineering Staff, before the Lawrence Institute of Technology freshman class, Detroit, December 4; title: A Young Engineer Views the Automotive Industry.

Edward G. Lommel, plant engineer, Plant Engineering Department, Detroit Transmission Division, before General Motors Institute students, Plymouth, Michigan, December 6; title: What Are Your Opportunities in Plant Engineering.

John G. Brian, Jr., manager, Production Engineering Department, Brown-Lipe-Chapin Division, before the Junior Achievement Group, Elyria, Ohio, December 10; title: Engineering Opportunities.

Arthur Birchenough, plant engineer, Plant Engineering Department, Brown-Lipe-Chapin Division, before the Elyria High School P.T.A., Elyria, Ohio, January 21; title: Correlation between Science Courses and Industry.

Joseph M. Rodgers, general supervisor, Electrical Test Laboratories, Delco Products Division, before students of Vandalia High School, Vandalia, Ohio, February 5; title: I Like Engineering.

Foundry

J. F. Orloff, general superintendent, Central Foundry Division, before the Michiana Foundry Group, Mishawaka, Indiana, January 13; title: Gating and Pouring Techniques to Reduce Scrap.

D. F. Richter, superintendent, Experimental and Development Department, Central Foundry Division, before the General Motors Institute Foundrymen's Association, Flint, January 14; title: Proper Gating Through the Use of Cobalt 60.

C. F. Joseph, technical director, Central Foundry Division, before the M.F.S. Technical and Operating Conference, Cleveland, February 6; title: Relationship of Practice to Properties.

Manufacturing

Jack Dunkle, superintendent, Production Engineering Department, AC Spark Plug Division, before the American Society of Mechanical Engineers, New York City, December 5; title: Economics of Mechanization.

C. J. Leistner, senior experimental chemist, Production Laboratory—Metallurgical, Allison Division, before the Indiana Spectrographers Society, Indianapolis, September 9, and before the Fourth Ottawa Symposium on Applied Spectroscopy, Ottawa, Canada, September 11; title: An Arc Method for Sample Transfer in Spectrochemical Analysis. Mr. Leistner also spoke before the American Association of Spectrographers, Western Society of Engineers, Chicago, December 10; title: Metal Transfer Techniques Used in Spectrochemical Analysis.

Clarence G. Chambers, supervisor, Laboratories, GM Process Development Staff, before the National Industrial Electric Heat Conference, Cincinnati, February 3; title: Industry's Evaluation of Electric Heat.

Ronald A. Featherstone, senior project engineer, Process Development Section, GM Process Development Staff, before the Industrial Management Council of Rochester, New York, January 6; title: Rapid Transition of Product from Engineering to Production.

Glen R. Fitzgerald, director, Equipment Sales and Automotive Engineering Department, AC Spark Plug Division, before the S.A.E. Annual Winter Meeting, Detroit, January 13; panel chairman on Foreign Production Methods, and before the National Automotive Parts Association, Houston, Texas, February 3; title: The Car of Tomorrow and its Effect on the Future of the Parts Business.

Charles A. Nichols, technical assistant to the vice president in-charge-of GM Process Development Staff, before the S.A.E., Twin City section, Minneapolis, January 23; title: Manufacturing Development as a Staff Function.

John E. Panek, project engineer, Process Development Section, GM Process Development Staff, before the Hydraulic Education Group, GM Technical

Center, Warren, Michigan, January 30; title: Use and Application of Fire Resistant Fluids.

Metallurgy

Stewart J. Harger, assistant chief development engineer, Manufacturing Development Engineering Department, AC Spark Plug Division, before the American Electroplaters Society, Jackson, Michigan, November 5; title: Protective Chromate Treatment on Zinc Plate and Zinc Base Die Castings.

Lester Sharrock, senior engineer, Product Engineering Department, Brown-Lipe-Chapin Division, before the American Electroplaters Society, Toledo, Ohio, December 28; title: Controlling Factors Governing Characteristics of Deposits.

Miscellaneous Subjects

Ralph A. Richardson, head, Administrative Engineering, GM Research Staff, before the Society of Technical Writers and Editors, New York City, November 13; title: A New Method of Writing Research Reports.

Eric J. Opitz, senior engineer-in-charge, tool design, Production Engineering Activity, Fisher Body Division, before the A.S.M.E. Education Session, New York City, December 2; title: Integration of Knowledge and Know-How.

L. W. Tobin, Jr., chief engineer, Automotive Engineering Department, AC Spark Plug Division, before the Annual Conference of the Automotive Electric Association, Chicago, December 9; title: What We May Expect in the Car of Tomorrow.

Fred Jantz, senior design group leader, Product Engineering Department, Oldsmobile Division, before the American Society for Engineering Education, Flint, January 17; title: The Use of Graphic Illustrations in Industry.

Wallace E. Wilson, general manager, Rochester Products Division, before the Rochester, New York, Salesmen's Club, January 20; title: There Are Dollars in Your Attitude.

William H. Lichty, instructor, Product Engineering Department, General Motors Institute, before the Flint, Michigan, Lions Club, January 22; title: Horse Power and Safety.

Zora Arkus-Duntov, assistant staff engineer, special design, Chevrolet Motor Division, before Corvette Owners Clubs, Denver, January 21; San Francisco, January 23; and Los Angeles, January 24; title: The Chevrolet Corvette.

Dr. R. W. Smith, supervisor, Physics and Metallurgy, AC Spark Plug Division, before the Northern Ohio Section of the American Ceramic Society, Cleveland, February 3; title: Creative Thinking.

Missile Guidance System Engineering

Engineering personnel of AC Spark Plug Division's Milwaukee, Wisconsin, facility who made recent presentations are as follows:

Donald Kelley, engineer, before Air Force Reserve personnel, Milwaukee, December 22; title: Inertial Guidance.

Tom O'Connell, technical director, Regulus II program, before the American Institute of Electrical Engineers Electronics Discussion Group, Milwaukee, January 8; title: Inertial Navigation—A Practical Application of Precision Measurement and Control.

Kenneth Schlager, engineering director, Regulus II program, before the Engineer's Club of Kimberly Clark Corporation, Menasha, Wisconsin, January 15; title: Missile Guidance Systems.

Charles Cusimano, senior engineer, before the Engineer's Club of Kimberly Clark Corporation, Menasha, Wisconsin, January 20; title: Missile Guidance Systems.

John Losse and **Arthur Sorensen, Jr.,** test engineers, before the Institute of Environmental Engineers, Chicago, January 22; title: Design Aspects of Vibration Fixtures.

Hans Hauser, senior project engineer, before the Bay Shore Lion's Club, Bay Shore, Wisconsin, January 22; title: Inertial Guidance for Missiles; before the Whitefish Bay Men's Club, Whitefish Bay, Wisconsin, January 30; title: Missiles—from Launch to Target; and before the staff group of the Durant Manufacturing Company, February 13; title: Missiles and Application of Inertial Guidance.

William French, project manager, Matador TM-76 missile, before the Northwest Kiwanis Club, Milwaukee, February 10; title: AC's Part in the Missile Program.

Dr. James Bell, technical director, Matador TM-76 missile, before the Kiwanis Club, Oconomowoc, Wisconsin, February 17; title: Missiles and Missile Guidance.

Sid Hatch, administrative assistant to project director, before the Wisconsin Society of Professional Engineers, Racine, Wisconsin, February 18: title; Planning the Guidance System Test Program.

David Matzke, bombing navigation systems engineer, before a Wauwatosa High School group, Wauwatosa, Wisconsin, February 19; title: Boolean Algebra.

Research

C. R. Russell, consulting engineer, Nuclear Power Engineering Department, GM Research Staff, before the Birmingham, Michigan, Junior Chamber of Commerce, November 21; title: The Problems of Site Selection for Nuclear Reactors, and before the A.S.M.E. Nuclear Gas Turbine Session, New York City, December 3; title: Gas Cooled Reactors for Civilian Applications.

Robert V. Coleman, senior research physicist, and **Gifford G. Scott,** research associate, Physics Instrumentation Department, GM Research Staff, before the Washington Conference of Magnetism and Magnetic Materials, Washington D.C., November 21; title: Magnetic Domain Patterns of Iron Whiskers.

Robert Herman, assistant chairman, Basic Science Group, GM Research Staff, **R. Rothery,** Wayne State University, and **R. J. Rubin,** National Bureau of Standards, before the American Physical Society, St. Louis, November 30; title: Line Intensities in Vibration-Rotation Bands of Diatomic Molecules.

Robert H. Kohr, supervisor, Engineering Mechanics Department, GM Research Staff, before the Eastern Joint Computer Conference, Washington D.C., December 10; title: Applications of Computers to Automobile Control and Stability Problems.

J. P. Gillilan, assistant chief engineer, Product Engineering Department, New Departure Division, before the American Ordnance Association, New York City, December 11; title: Isoelasticity.

Charles A. Amann, supervisor, Engineering Development Department, GM Research Staff, before the A.S.M.E., Washington D.C., December 12; title: Working Fluid Considerations in Closed Cycle Gas Turbines.

A Typical Problem in Engineering:

Determine the Thermal Deflection of a Composite Beam

By HENRY S. McLIMORE
Allison Division
and GEORGE W. GROTTS
General Motors Institute

A frequently used component of a temperature measuring device is the bimetal strip composed of two metals having different coefficients of thermal expansion. Of interest to the engineer is the amount one end of the strip will deflect when at a specific temperature. In the analysis of such a deflection problem the bimetal strip is considered as a composite beam. It must be kept in mind, however, that the strains obtained are combinations of temperature extensions and bending deformations.

A bimetal strip presents an interesting deflection problem

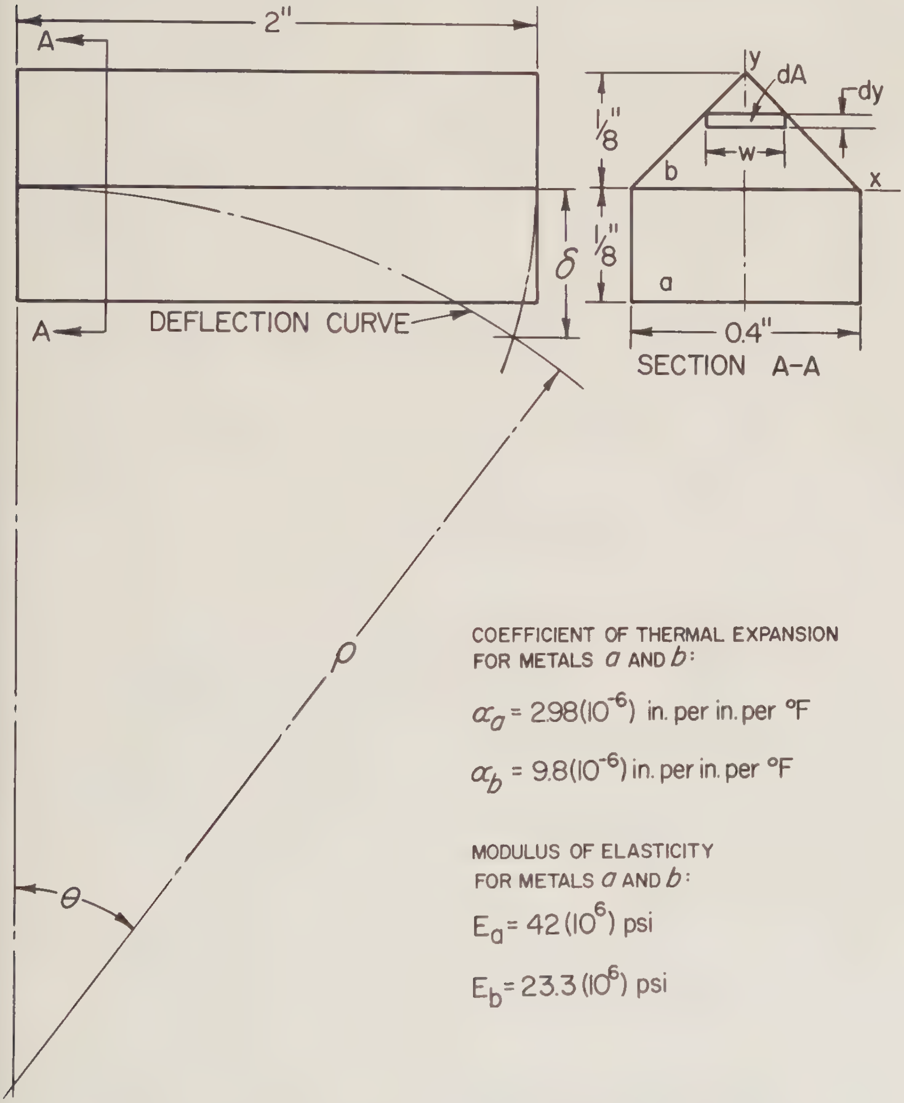

2"
A
A
DEFLECTION CURVE
δ
1/8"
1/8"
y
dA
dy
w
b
x
a
0.4"
SECTION A-A
ρ
θ
COEFFICIENT OF THERMAL EXPANSION FOR METALS a AND b:
αa = 2.98(10^-6) in. per in. per °F
αb = 9.8(10^-6) in. per in. per °F
MODULUS OF ELASTICITY FOR METALS a AND b:
Ea = 42(10^6) psi
Eb = 23.3(10^6) psi

Fig. 1—A bimetal strip composed of metals a and b, each having the coefficient of thermal expansion α and modulus of elasticity E indicated, is straight when at room temperature. When the temperature of the strip is increased T°F there is an end deflection δ and a radius of curvature ρ. It can be assumed that section *A-A* of the strip remains plane after the strip has deflected. Since there are no external forces or moments on the strip to the right of section *A-A* the sum of the forces normal to this section is zero and the sum of the moments of these forces about line x is zero. An element of force acts on an element of area dA which has a width w and a height dy. The specific values given for E are at a temperature of 1,000°F above room temperature.

A FREQUENT occurrence encountered in gas turbine engine developmental work is the accurate measurement of temperature. Recently, temperature measurements were required at selected points along the radius of a turbine wheel in a gas turbine engine. To provide these measurements a device was proposed consisting of several parts, one of which was a bimetal strip to be used as the temperature-sensing component. Each piece of the strip was of constant cross section symmetrical with respect to a line perpendicular to their common side. Before the device could be used it became necessary to determine the deflection of one end of the bimetal strip relative to the other end as the temperature increased, due to the hot gases in the turbine section.

The problem is to calculate the end deflection δ of the bimetal strip (Fig. 1) after a temperature increase of 1,000°F. The bimetal strip can be considered a composite beam.

Since there are no forces or moments external to the beam at the right of section *A-A*, it can be concluded that the sum of the forces normal to this section must be zero and the sum of the moments of these forces about any line—line x, for example—must be zero. An analytical expression can be set up, therefore, for the unit stress s acting on an element of area dA at section *A-A*. This unit stress can be written in terms of unit strain ε. The unit strain, in turn, can be expressed in terms of the radius of curvature ρ and strain ε_0, both measured at the interface of the two metals. With this information the radius of curvature can then be determined and the deflection δ computed.

The solution to the problem will appear in the July-August-September 1958 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

Solution to the Typical General Motors Institute Laboratory Problem:

Determine the Unbalanced Forces in a Converted V-8 Engine

To provide a more versatile test engine for mechanical engineering laboratory work at General Motors Institute, a production V-8 engine was converted to a four cylinder engine. Removal of the four middle cylinders required that the engine be rebalanced. The unbalanced forces resulting from removal of the four cylinders had to be determined first and the engine then rebalanced. This is the solution to the problem presented in the January-February-March 1958 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

INERTIA FORCES AND MOMENTS

	CRANKPIN NUMBER	INERTIA FORCE (F)	MOMENT ARM (ℓ)	MOMENT (M)
HORIZONTAL PLANE	I	$2Q(\sin^2\alpha \sin\theta)$	$\frac{3L}{2}$	$\frac{3LQ}{2}(\sin\theta)$
	II	$Q=0, F=0$	$\frac{L}{2}$	0
	III	$Q=0, F=0$	$-\frac{L}{2}$	0
	IV	$2Q \sin^2\alpha \sin(\theta+180°) = -2Q(\sin^2\alpha \sin\theta)$	$-\frac{3L}{2}$	$\frac{3LQ}{2}(\sin\theta)$
	TOTAL	$F=0$		$M_H = 3LQ(\sin\theta)$
VERTICAL PLANE	I	$2Q(\cos^2\alpha \cos\theta)$	$\frac{3L}{2}$	$\frac{3LQ}{2}=(\cos\theta)$
	II	$Q=0, F=0$	$\frac{L}{2}$	0
	III	$Q=0, F=0$	$-\frac{L}{2}$	0
	IV	$2Q\cos^2\alpha\cos(\theta+180°) = -2Q(\cos^2\alpha\cos\theta)$	$-\frac{3L}{2}$	$\frac{3LQ}{2}(\cos\theta)$
	TOTAL	$F=0$		$M_V = 3LQ(\cos\theta)$

$$M_T = \sqrt{(M_V)^2 + (M_H)^2} = \sqrt{(3LQ\sin\theta)^2 + (3LQ\cos\theta)^2} = 3LQ$$

$$\Sigma M_V = 3LQ\cos\theta$$

$$\Sigma M_{V(MAX)} = 3LQ \text{ (when } \theta = 90° \text{ and } \cos\theta = 1)$$

$$\Sigma M_H = 3LQ\sin\theta$$

$$\Sigma M_{H(MAX)} = 3LQ \text{ (when } \theta = 90° \text{ and } \sin\theta = 1)$$

Table I—Tabulated above are the inertia forces F and moments M acting on the crankshaft when in the horizontal and vertical planes. Shown below the Table is a derivation for a general expression for the summation of inertia forces and moments resulting from the reciprocating weight. In the Table, L is the distance between crankpin centerlines; Q is a centrifugal force constant due to the reciprocating weight (Table II); α represents one-half the engine bank angle, or 45°; and Θ is the angular displacement of the number I crankpin from the vertical position. The total moment M_T resulting from the reciprocating weight is $3LQ$. The summation of moments due to the reciprocating weight is $3LQ(\sin\Theta)$ in the horizontal plane and $3LQ(\cos\Theta)$ in the vertical plane. The maximum vertical moment M_V occurs when $\Theta = 0°$ and the maximum horizontal moment occurs when $\Theta = 90°$. The angle Θ was assumed to be 0°. The total reciprocating weight moment, therefore, occurs in the vertical plane.

TO BALANCE the converted V-8 engine required the application of basic principles of engine balance. The first step was to obtain a general expression for the summation of inertia forces and moments resulting from the reciprocating weight W. This weight was stated as 1.90 lb in the problem. Since the pistons and rods were removed from the middle four cylinders there is no reciprocating weight on crankpins II and III. The forces and moments at these crankpins, therefore, are zero (Table I).

After the summation of inertia forces and moments resulting from the reciprocating weight was completed, the next step was to evaluate the maximum moment due to the reciprocating weight for the converted engine (Table II).

The rotating mass centrifugal forces were then calculated, using known data for the crankpins and cheeks, or counterweights. The radius vectors were first resolved into horizontal and vertical components. The centrifugal forces and their resulting moments were then calculated and tabulated (Table III). A moment summation also was made to determine the total unbalance in each plane.

Since the crankshaft was originally designed and built to balance eight pistons and eight connecting rods, the disposition of these centrifugal forces must be evaluated to determine their effect in the converted engine. If a derivation similar to Table I is made for the engine with eight pistons and eight connecting rods the following values for the summation of moments in the vertical

Presented here is the solution to a typical problem assigned to students enrolled in advanced laboratory course work at General Motors Institute. The problem is illustrative of how design classes are integrated with mechanical engineering laboratory work. Data obtained from the laboratory were used in the design class. The concepts developed in the design class were then tested and evaluated in the laboratory.

Faculty Member-in-Charge:
ELWOOD K. HARRIS

G.M.I. Cooperative Students:
ERIC MITTELSTADT
GM Engineering Staff

WERNER HELLER
Adam Opel A.G.
Russelsheim/Main, Germany

RAY TORBIT
Cadillac Motor Car Division

Basic principles of dynamics and mechanics applied to balance a unique engine

and horizontal planes will be obtained:

Summation of moments in vertical plane $= QL(3 \cos \Theta + \sin \Theta)$

Summation of moments in horizontal plane $= QL(\cos \Theta - 3 \sin \Theta)$.

It should be noted that the maximum value for the vertical moment occurs when the number I crankpin has turned 18°24′ from the vertical. The maximum value at this position is $3.16LQ$.

When the crankpin is vertical the summation of moments for the V-8 engine is $3LQ$. This is the same as in the converted engine with the four pistons removed. Similarly, when the number I crankpin is vertical there is a "built in" horizontal moment. This moment can be evaluated by substituting 0° in the equation which states the summation of horizontal moments for the original engine. The crankshaft for the original V-8 engine also had counterweights to counteract the centrifugal force due to the rotating weight of the four connecting rods on crankpins II and III.

Summary

The numerical values obtained for the converted four cylinder engine (Fig. 1) in the solution agree with the above evaluation for the original V-8 engine within the limits of accuracy used to establish the center of gravity of the cheeks and crankpins. When the engine

MAXIMUM MOMENT DUE TO RECIPROCATING WEIGHT

Q = centrifugal force constant due to reciprocating weight

$$Q = \frac{mV^2}{R} \qquad (1)$$

where

Q = centrifugal force (lb)
m = mass (slugs)
V = velocity (in. per sec)
R = moment arm (in.)

$$m = \frac{W}{g}$$

where

W = weight (lb)
g = acceleration due to gravity = 386.4 in. per sec^2

$$V = \omega R$$

where

ω = angular velocity (radians per second)

Substituting into equation (1):

$$Q = \frac{\frac{W}{g}(\omega R)^2}{R} = \frac{W\omega^2 R}{g} \cdot \qquad (2)$$

$$\omega = \frac{2\pi N}{60}$$

where

N = rotational speed (rpm)

Substituting into equation (2):

$$Q = \frac{W\left(\frac{2\pi N}{60}\right)^2 R}{386.4} = 0.0000284\, N^2 WR. \qquad (3)$$

Known data:

N = 3,000 rpm
W = reciprocating weight = 1.90 lb
R = 1/2 the stroke = 1.5 in.

Substituting into equation (3):

$$Q = 0.0000284(3{,}000)^2(1.90)(1.5)$$

$$Q = 729 \text{ lb.}$$

Maximum moment due to reciprocating weight $= M_V$

$$M_V = 3LQ$$

$$M_V = 3(4.4)(729)$$

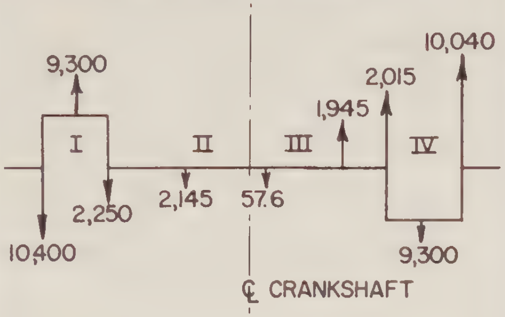
$$M_V = 9{,}620 \text{ lb-in.}$$

Table II—The maximum reciprocating weight moment occurs in the vertical plane and is equal to $3LQ$. The factor Q is a centrifugal force constant due to the reciprocating weight. Shown above is the derivation of this constant Q. The maximum moment due to the reciprocating weight is equal to 9,620 lb-in.

	MOMENTS DUE TO ROTATING MASS CENTRIFUGAL FORCES			
	CRANKPIN OR CHEEK NUMBER	CENTRIFUGAL FORCE (LB)	MOMENT ARM ℓ (IN.)	RESULTING MOMENT (LB-IN.)
VERTICAL PLANE	I	1,410	6.6	9,300
	II	0	2.2	0
	III	0	2.2	0
	IV	1,410	6.6	9,300
	1	1,282	8.1	10,400
	2	425	5.3	2,250
	3	612.5	3.5	2,145
	4	0	0.9	0
	5	64	0.9	57.6
	6	555	3.5	1,945
	7	380	5.3	2,015
	8	1,230	8.15	10,040
HORIZONTAL PLANE	I	0	6.6	0
	II	645	2.2	1,420
	III	645	2.2	1,420
	IV	0	6.6	0
	1	0	8.1	0
	2	590	5.3	3,130
	3	355	3.5	1,240
	4	265	0.9	238.5
	5	239	0.9	215
	6	390	3.5	1,365
	7	390	5.3	2,070
	8	0	8.15	0

a

SUMMATION OF VERTICAL MOMENTS (INCLUDING RECIPROCATING WEIGHT AND ROTATING WEIGHT)



CLOCKWISE MOMENTS	COUNTER-CLOCKWISE MOMENTS
9,300.0	10,400
57.6	2,250
9,300.0	2,145
9,620.0*	1,945
28,277.6	2,015
	10,040
	28,795

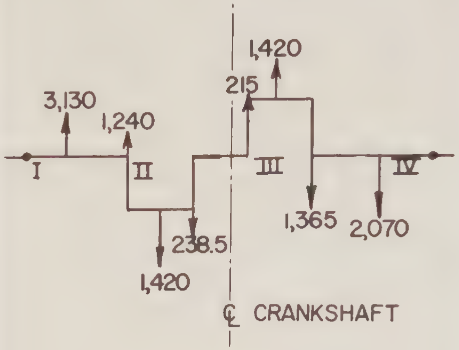
M = 28,795 − 28,277.6

M = 517.4 LB-IN. (COUNTERCLOCKWISE)

*MOMENT DUE TO RECIPROCATING WEIGHT

b

SUMMATION OF HORIZONTAL MOMENTS



CLOCKWISE MOMENTS	COUNTER-CLOCKWISE MOMENTS
3,130	1,420.0
1,240	238.5
1,365	215.0
2,070	1,420.0
7,805	3,293.5
	(3,380*)

M = 7,805 − 3,293.5

M = 4,511.5 LB-IN. (CLOCKWISE)

*MOMENT DUE TO ROTATING WEIGHTS ADDED TO CRANKPINS II AND III

c

Table III—The rotating mass centrifugal forces are calculated by first determining the value of *Q* for each crankpin and cheek and then resolving the resulting vectoral forces into their horizontal and vertical components. These components, when multiplied by their respective moment arms, give the moments of the various crankpins and cheeks about the centerline of the crankshaft in the horizontal and vertical planes (a). Shown at (b) and (c) is a summation of moments in the vertical and horizontal planes. It should be noted that the reciprocating weight moment is included only in the vertical plane moment summation, since Θ was assumed equal to 0°. This reciprocating weight moment is in a clockwise direction since it is a moment produced by centrifugal forces acting on the number I and number IV crankpins of the converted engine.

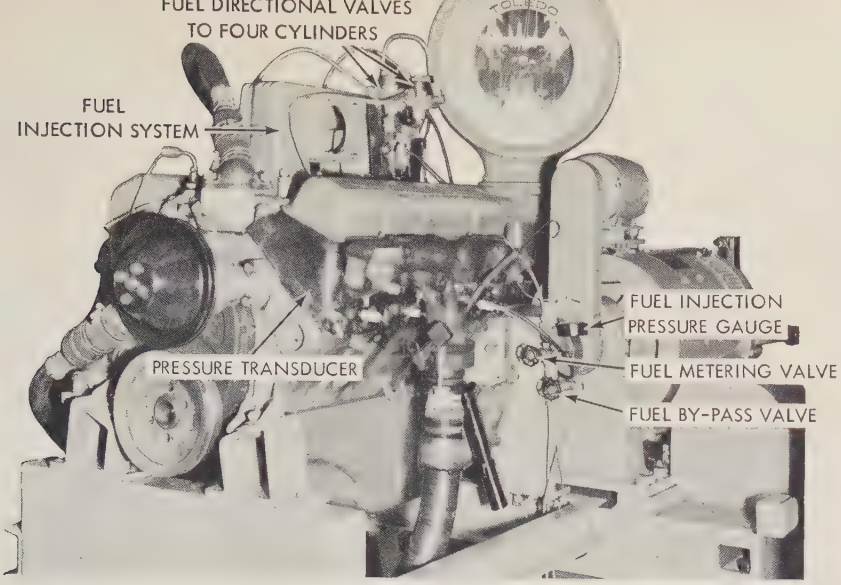


Fig. 1—Shown here is a view of the converted V-8 engine currently being used in mechanical engineering laboratory work at General Motors Institute. The pistons and connecting rods from the four middle cylinders were removed to allow convenient placement of pressure pickups used for combustion cycle analysis.

was actually rebuilt weights were clamped to crankpins II and III to correspond to the rotating weights of the four connecting rods which were removed. Additional weight also was added to compensate for the horizontal moment.

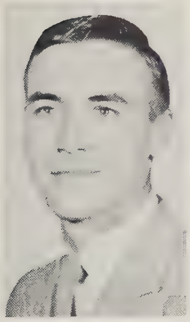
As indicated in the solution, the counterweights designed for the original V-8 engine crankshaft are still somewhat "too heavy," even after adding weights (representing the rotating weight of the connecting rods which were removed) to crankpins II and III. The converted engine, with the counterweights clamped to the intermediate crankpins, was motored to check the complete assembly for vibration. The engine was mounted rigidly by welded steel members. In operation, the engine vibration was hardly perceptible. The converted engine now is in use for mechanical engineering laboratory classes.

Correction to the Previous Typical G.M.I. Laboratory Problem

Attention has been called to three errors which appeared in Fig. 1, page 57, of the Typical G.M.I. Laboratory Problem presented in the January-February-March issue of the General Motors Engineering Journal. The errors and their corrections are as follows:

1) The view showing the location of β, the angle of center of gravity location with respect to the centerline of the number I crankpin, was shown incorrectly as a rear view. This view should be a front view.
2) The tabulated values for β for crankpins III and IV were given as 180° and 90°, respectively. These values should be corrected to read $\beta = 90°$ for crankpin III and $\beta = 180°$ for crankpin IV.
3) The counterweight shown on cheek number 5 should have been shown on cheek number 6 instead.

Student Contributors to the General Motors Institute Laboratory Problem



WERNER H. HELLER, is presently a group leader for engine accessories (designing) with Adam Opel A. G. in Russelsheim/Main, Germany. He joined Adam Opel in 1953 after receiving an engineering degree from the Engineering Institution, Mannheim, Germany. His first two years with Adam Opel were spent in the Engineering Department. Mr. Heller came to the United States in 1955 to attend General Motors Institute on the GM Overseas Scholarship Plan. In 1957 he received a special 3rd and 4th year Certificate from G.M.I. and then returned to Adam Opel. His cooperative plant assignments while at G.M.I. were with AC Spark Plug Division in Flint.

ERIC MITTELSTADT, is an engineering graduate-in-training with the Passenger Car Development Group of the GM Engineering Staff. He is presently participating in the G.M.I. Fifth-Year Program which, when completed, will qualify him for a B.M.E. degree. His Fifth-Year project study is concerned with an investigation of body-frame integral construction of passenger cars. He joined the Engineering Staff in 1953 as a G.M.I. co-op student. His work assignments during the four year co-op program were with the Test Facilities Section and the Passenger Car Development Group. He is a member of Alpha Tau Iota, honorary society, and the Society of Automotive Engineers.

RAY TORBIT, joined Cadillac Motor Car Division in 1953 as a G.M.I. co-op student. During the first two years of the cooperative program his plant assignments included work in the Production Planning, Final Assembly, Public Relations, and Cost Estimating Departments. His plant assignments during the third and fourth year of the program were in the Engineering Department where he gained experience in design, laboratory test work, and engineering specifications. He is presently participating in the Fifth-Year Program as a senior detailer in the Engineering Department. His Fifth-Year project study deals with design factors affecting low speed torque and their probable effects on car performance.

A Typical Problem in Engineering:

Find the Resistance Values of a Thermocouple-Potentiometer Circuit

Temperature is one of the most frequent and important measurements made in industry. The majority of temperature measurements in engineering work are made by using thermocouples and potentiometers. Potentiometers are very versatile since they can be modified easily to meet a variety of instrumentation applications. The temperature range and thermocouple type of potentiometer can be altered simply by changing some of the measuring-circuit resistors. There are standard temperature ranges for which the required resistors are commercially available. Special temperature ranges, however, require that special circuit resistors be wound by hand. The problem presented here is one frequently encountered by the Instrumentation Section of the GM Research Staff. The problem is to find the values of the resistors necessary to give a potentiometer circuit a special temperature range.

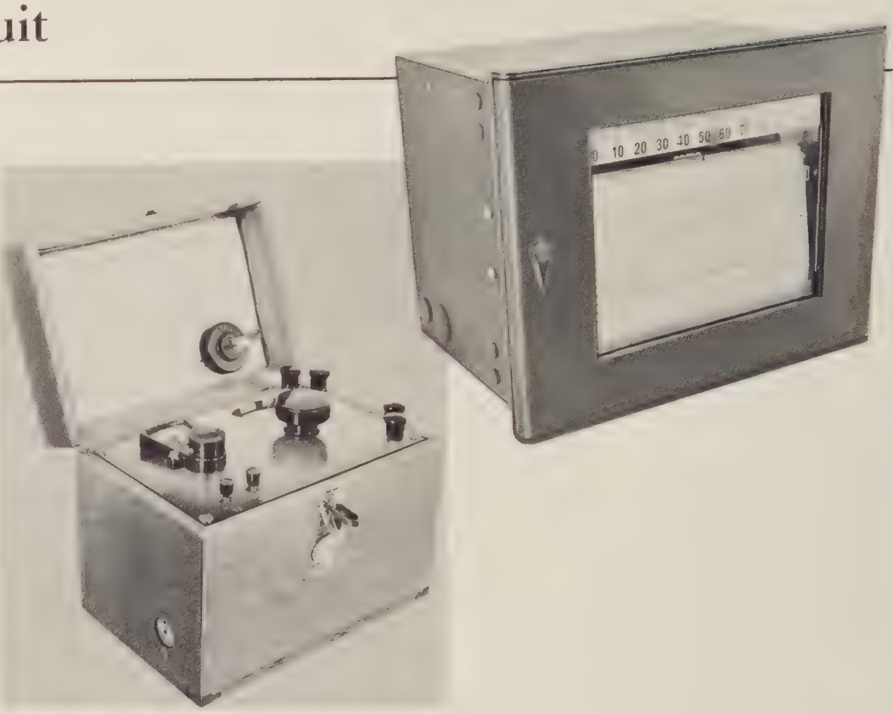


Fig. 1—Potentiometers are very versatile instruments and, when combined with thermocouples, make excellent temperature measuring devices. The portable potentiometer (left) is used extensively in making laboratory measurements of temperature. The portable potentiometer requires manual manipulation in both standardizing and measuring. Also, automatic reference junction compensation is used. Recording potentiometers (right) are used for both laboratory and industrial temperature measurement work. The recording potentiometer contains a null-balance electronic amplifier which replaces the usual galvanometer. The amplifier powers a two-phase reversible motor which positions automatically a slidewire contact and pen through suitable cables and pulleys. A continuous recording and temperature indication is thus obtained. A timing device and clutch mechanism are used to standardize automatically the bridge current at periodic intervals.

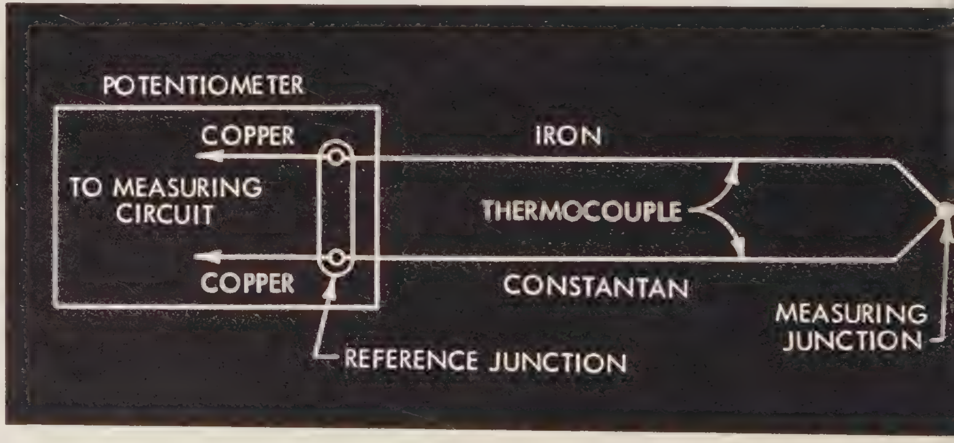


Fig. 2—When a thermocouple is used to measure temperature, the instrument always introduces its own two junctions. However, by virtue of their being very close together and at the same temperature, they function as a single junction. This is known as the reference junction. The junction external to the instrument (in this case a potentiometer) is called the measuring junction. The instrument actually measures the algebraic sum of the emfs developed at both the reference and measuring junctions. This emf is thus a function of the temperature difference. To obtain an absolute temperature reading the reference junction must be known or compensated to some base temperature.

A THERMOCOUPLE junction consists of two dissimilar metals, usually in wire form, joined mechanically by either welding, soldering, or brazing. Such a junction has the property (Seebeck effect) of producting an emf across the interface of the two different metals. The emf developed is a function of the temperature and the metal compositions. For commonly used thermocouple metals, the emf developed is nearly directly proportional to the temperature at the junction. Since the emf versus temperature relationship is known, it is necessary only to measure this emf to determine the temperature.

Because potentiometers are versatile instruments they are frequently used with thermocouples for temperature measurement work (Fig. 1). When a thermocouple is combined with any instrument, however, it is impossible to measure the emf of a single junction, thereby obtaining temperature directly, because the instrument introduces additional junctions (Fig. 2). The two junctions at the

By **RUSSELL V. FISHER**
General Motors
Research Staff
Assisted by Kenneth W. Woodfield
General Motors Institute

Resistors must give the circuit a special temperature range

instrument function as a single junction, known as the reference junction. The junction external to the instrument is called the measuring junction. The instrument measures the algebraic sum of the emfs developed at both the reference and measuring junctions.

The thermocouple-potentiometer circuit (Fig. 3) is basically a Wheatstone bridge. Current is supplied from a battery. A rheostat in the battery circuit is varied to maintain the current at a constant value as the battery ages. This operation is called *standardization* and must be performed periodically to insure accurate temperature measurement.

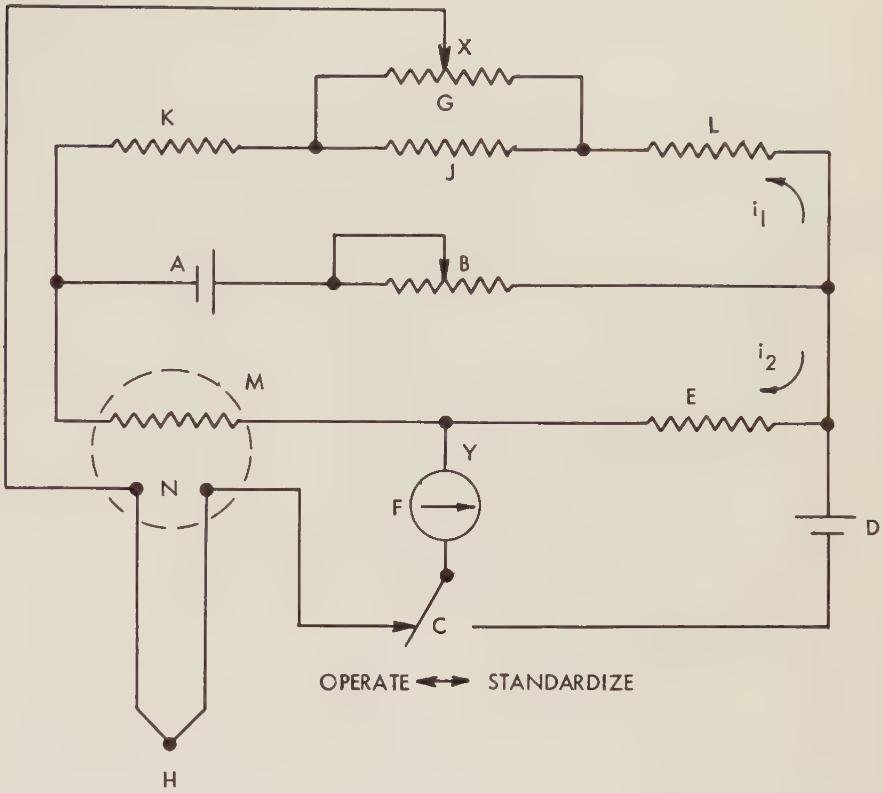


Fig. 3—The circuit of a thermocouple-type potentiometer is basically a Wheatstone bridge. The circuit is designed so that currents i_1 and i_2, supplied from battery A, are equal. A rheostat B in the battery circuit is varied to maintain the currents at a constant value as the battery ages. This operation is called *standardization* and must be performed periodically to assure accurate temperature measurements. The standardization procedure is accomplished by actuating a standardizing switch C connecting standard cell D across a standardizing resistor E. The standardizing rheostat B is then adjusted until the galvanometer F (or an electronic null-balance amplifier, if used) indicates zero. The voltage drop across resistor E will then exactly equal the standard cell voltage. The bridge current is now standardized at the proper value. With the standardizing switch in the "operate" position, the thermocouple emf is compared to the voltage between points X and Y. Slidewire G is then adjusted until the galvanometer indicates zero current. Since the slidewire is calibrated in temperature the position of the slidewire contact is a direct indication of the temperature at the measuring junction H.

The desired temperature span of the instrument is obtained by altering the slidewire shunt J in parallel with slidewire G. The slidewire is the same for all temperature ranges. This is because it is extremely difficult to manufacture slidewires themselves to the exact precision and resistance value necessary. Also, it would be necessary to change the slidewire each time the temperature range to be measured is changed.

The voltage drop across G and J in parallel must equal the span of the thermocouple emf. The lower suppression resistor K is selected to give the temperature value at the lower end of the scale. This value is generally 0°F. Sometimes, however, it is desirable to suppress the zero. For example, a temperature range of 1,000°F to 2,000°F may be required. Resistor K also can be adjusted to give a low-scale temperature in the below-zero region.

The current limiting resistor L is used to limit the current in the upper arm of the bridge and must be accurately constructed. Its resistance value must be calculated to one extra significant figure. The reason for this is that the voltage drop across L is greater than the voltage drop across G. A small percentage error in L, therefore, becomes a large percentage error in the calibration of G.

All resistors in the circuit, except the reference junction compensating resistor M, are made of manganin wire which has a negligible temperature coefficient of resistivity. Resistor M is made from wire which has a large temperature coefficient because this resistor is used to compensate for temperature changes at the thermocouple reference junction N. The reference junction is usually buried in the coil of resistor M so that an ambient temperature change will affect both simultaneously. With this arrangement the emf at point Y will vary and compensate for reference junction temperature drift.

Problem

The problem is to determine the values of resistors E, J, K, and L (Fig. 3) for a temperature range of 300°F to 900°F using iron versus constantan thermocouples. The value for the reference junction compensating resistor M also is to be determined at a temperature of 75°F.

Information pertinent to the solution of the problem is as follows:

- Resistance of slidewire $G = 25$ ohms
- Currents $i_1 = i_2 = 0.005$ amperes (This gives adequate galvanometer sensitivity with reasonable battery life)
- Standard cell voltage $= 1.0190$ volts.

Values for the emf of the iron-constantan thermocouples, from tables based on a reference junction at 0°F, are as follows:

0°F = 0 volts
75°F = 0.00216 volts
300°F = 0.00887 volts
900°F = 0.02733 volts.

The temperature coefficient of resistance for the reference junction compensating resistor M equals 0.0028 ohms per ohm °F at 0°F. This coefficient is to be assumed constant over the ambient temperature range. The solution to the problem will appear in the July-August-September 1958 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

GM Engineers Develop Electro-Magnetic Guidance System to Steer Vehicles Automatically

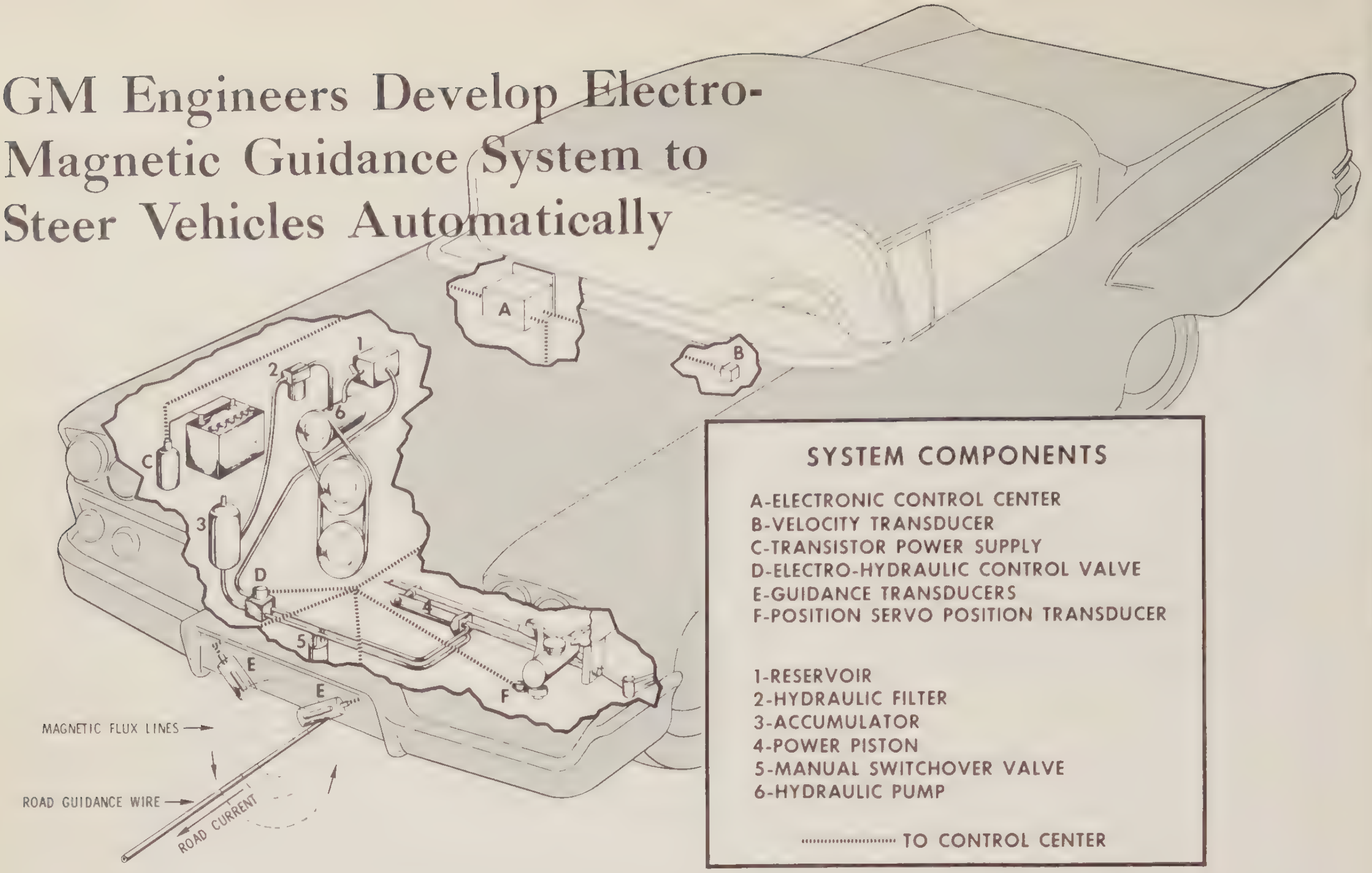


Fig. 1—Shown here are the components of the automatic guidance control system. The various control components are designated by letters, and the hydraulic power steering components are designated by numbers. The electronic analog computer *A* powered by the transistor power supply *C* receives input signals from the guidance transducers *E*. These transducers sense the position of the vehicle relative to the road guidance cable in the highway. The computer modifies this information with signals received from the velocity transducer *B*, which coordinates the steering gain with velocity. The modified signal is sent to the electro-hydraulic control valve *D* and the position servo position transducer *F*. These two components control the position of the steering mechanism through the hydraulic power steering system (1—6).

The time-worn phrase, "Look Ma, no hands," was recently given a new meaning when GM Research Staff engineers demonstrated an automatically guided automobile on a one mile test strip at the GM Technical Center. The demonstration car was guided by a combined electronic computer and servo system which takes over for human steering control by following a magnetic path produced by low frequency power from a guidance cable. The development of the automatic control system indicated the possibility of a built-in guidance system for highways of tomorrow.

The control system is a "breadboard job" assembled to test the idea of electromagnetic vehicle guidance. It is the hardware phase of a system demonstrated in model form by the Radio Corporation of America in 1953.

The primary components of the automatic steering guidance control system (Fig. 1) include a road guidance power cable imbedded in the surface of the roadway; a pickup device which receives signals from the cable; an analog computer which transforms signals received from the pickup device into "command" signals; and a modified power steering system with servo controls which translate the command signals received from the computer into automatic steering action.

The road guidance power cable carries a low frequency alternating current. A circular magnetic field is produced and extends the length of the cable. On the front bumper of the car (Fig. 2) two tuned pickup coils are mounted and straddle the magnetic field produced by the cable. The voltage across the terminals of the pickup coils depends on the magnetic field strength. As the car follows the magnetic path, any deviation or lateral motion of the car causes a difference in voltage between the two coils. The voltage variations are fed to an electronic analog computer located in the glove compartment of the car (Fig. 3). The computer, in turn, is linked with a servo system which controls the modified power steering unit of the car. In effect, the computer measures the difference in voltage and automatically adjusts the steering onto the magnetic path through the servo system. The computer sends command signals to the servo mechanism, which positions the front wheels. Thus, when the car undergoes any deviation from its straight-ahead course, the automatic steering system brings it back into the straight-ahead path.

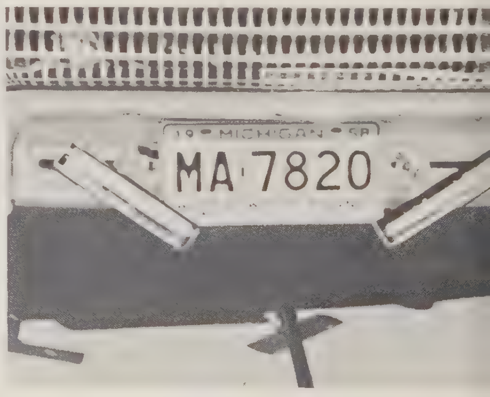


Fig. 2—The two tuned pickup coils on the front bumper straddle the magnetic field created by the power cable imbedded in the road. The guidance system automatically steers the car so that the strength of the magnetic field, as detected by the pickup coils, is equal in both coils.

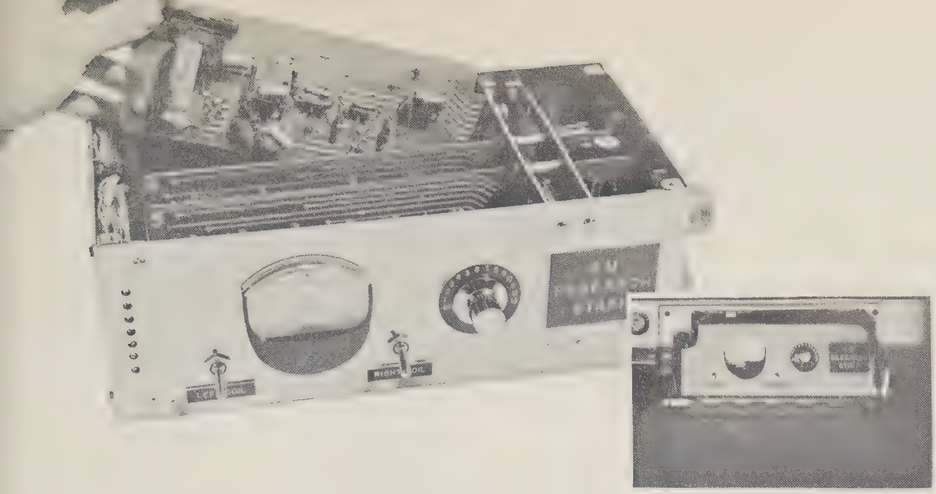


Fig. 3—This closeup shows the electronic analog computer which controls the electro-magnetic guidance system. The computer unit fits into the glove compartment (inset) and feeds command signals to the modified power steering system of the car.

To turn off the road or pass another vehicle the driver flicks a switch mounted on the steering gear, which places the car back into manual steering control. During the period that the car is under automatic steering gear operation the accelerator and brake continue to be controlled by the driver.

System Chosen for Ultimate Simplicity

Although other kinds of guidance systems could be applied to automobiles, Research Staff engineers chose the electro-magnetic system because of its ultimate simplicity. Among other things, the electro-magnetic system requires only low frequency power and has good sensitivity. Because the guidance power cable is imbedded in the surface of the road, weather and radiation interference is eliminated.

In its present form the system could easily be integrated into present-day highway networks, possibly in the form of a separate lane for cars equipped with the guidance device. This would make the system feasible during a transition period in which both conventional and automatically guided automobiles were using the highway.

Special Computer Developed to Solve Stability Problem

An important problem in the development of the automatic steering system was the stability and control of the system when substituting for human steering. This problem was solved by a series of studies with a special analog computer developed by the Engineering Mechanics Department of the Research Staff.

The analog computer was fitted with a steering wheel. Linked to the computer-steering wheel combination was a simulator with a miniature car controlled by servo mechanisms. The miniature car reacted to various inputs at the steering wheel just as a full-size car would react to the torques and displacements applied by the driver. Various steering and car handling equations were worked out on the laboratory computer-simulator set-up. These equations described mathematically how the steering system would respond to various driver reactions. Using these equations, engineers then developed the servo system to give the full-size test vehicle continuous, stabilized balance.

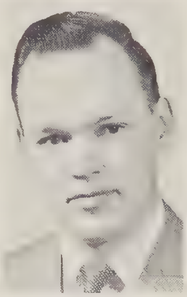
Conclusion

The automatic steering guidance control system is still in the research stage, although it has been installed and is presently being operated on a test car at the GM Technical Center. While limited at present to steering control it is thought of by Research Staff engineers as the first building block in what may become a more sophisticated system for controlling vehicle spacing, detecting locations of cars, or giving the driver signals for throttle and brake control.

It cannot be predicted what will evolve from this basic electro-magnetic steering guidance system. The new system, however, points out the ideas being explored and reflects an extension of a steady trend toward greater reliance on automatic devices for both vehicle operation and traffic control, as represented by such developments as automatic transmissions and electronic traffic signal systems.

Contributors to Apr.-May-Jun. 1958 Issue of

ENGINEERING JOURNAL



CHARLES A. AMANN, co-contributor of "Testing Paper Gas Turbines: Applying the Digital Computer to Engine Design," is supervisor of the Thermodynamic Design Section of the Engineering Development Department, General Motors Research Staff, located at the GM Technical Center, Warren, Michigan.

He joined the Research Staff as a student summer employe in 1948, and returned on a permanent basis in 1949. He was promoted to his present position in 1954.

Mr. Amann attended the University of Minnesota, where he received the B.S. degree in 1946 and the M.S. in Mechanical Engineering in 1948. He also was an instructor of mechanical engineering at Minnesota, and has taught evening classes at Wayne State University, Detroit.

Mr. Amann's previous work has included the design and development of turbo-machinery for gas turbine engines, free piston engines, and turbo-chargers. He also has worked on design studies of nuclear and aircraft gas turbines. Mr. Amann helped design gas turbine engines for the Firebird I and II, the Turbotitan, and the Turbocruiser, and the free piston engine for the XP-500, all of which are GM experimental vehicles.

He is now supervising the group responsible for the design and development of compressors and turbines, and for cycle analysis and performance studies of various power plants.

Mr. Amann is a member of the S.A.E., Tau Beta Pi, and Tau Omega.

EDWARD A. BENDER, co-contributor of "Magnetic Test Accurately Compares Heat Extraction Properties of Quenching Media," is a metallurgical engineer in the Process Development Section of the General Motors Process Development Staff, located at the GM Technical Center.

Mr. Bender joined General Motors in 1927 as an inspector in the Cadillac Motor Car Division. He was promoted to laboratory technician in 1936, and to heat treat supervisor in 1941. He became an experimental metallurgist in the Process Development Section in 1947.

Mr. Bender currently is engaged in metallurgical development in the heat treatment of metals. His previous work has included projects in the metallurgical structure and heat treatment for cold forming of alloy steels, control of distortion in heat treatment, and controlled atmospheres. He has developed methods for controlling distortion in fixture quenching by the application of differential pressures, and for heat forming automotive and Diesel piston compression rings to exert equal and radial pressures on the cylinder walls.

Mr. Bender, who attended Wayne State University, is a member of the American Society for Metals, serving on the tool committee.

DONALD E. BRINKERHOFF, co-contributor of "A Discussion of Some Factors Affecting Reproduced Radio Sound in an Automobile," is engineer-in-charge of the Acoustical Engineering Laboratory at Delco Radio Division, Kokomo, Indiana.

Mr. Brinkerhoff joined Delco Radio in 1945 as a specifications engineer and assumed his current position in 1952. His present responsibilities include loudspeaker and associated audio-acoustical system design and development.

Contributors' backgrounds vary greatly in detail but each has achieved a technical responsibility in the field in which he writes.

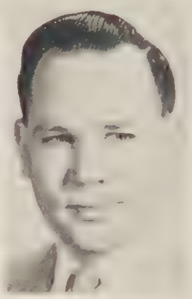
Mr. Brinkerhoff graduated from Purdue University in 1943 with a bachelor of science degree in electrical engineering. During World War II he served as an officer with the U.S. Army Signal Corps. After completing the Army Officers Electronics School at Harvard University and the Massachusetts Institute of Technology Radar School, he was appointed an instructor in electrical communication engineering at the M. I. T. Radar School. He also served as a member of the Army Ground Force Board II where he was responsible for new radar equipment evaluation.

The technical society affiliations of Mr. Brinkerhoff include membership in the Acoustical Society of America, the Professional Group on Audio in the Institute of Radio Engineers, the Audio Engineering Society, and the Kokomo Engineering Society.

HAROLD E. CHASSEE, contributor of "The Design and Development of a Synchronous Firing Device for Twin 40mm Guns," is a senior project engineer on turret and armament design at Cadillac Motor Car Division's Cleveland, Ohio, Ordnance Plant. In this position he is currently working on the design and development of a liquid spring recoil mechanism to replace the hydraspring recoil system now in use on most tank weapons.

Mr. Chassee joined General Motors in 1943 as a junior designer in the Engineering Department at Cadillac Motor Car Division in Detroit. Later that year he entered the armed forces and served as an instructor in communication and heavy weapons. After his discharge he rejoined Cadillac in 1946 as a sample body builder in the model shop. In 1948 he was transferred to the engineering laboratory as a project mechanic and performed evaluation tests pertaining to body design. In 1950 he was promoted to project engineer and was transferred to the Cleveland Ordnance Plant where he did design and developmental work on the 76mm, M-41 light tank. He assumed his present position in March 1951.

Mr. Chassee's technical affiliations include membership in the Society of Automotive Engineers and the American Ordnance Association.



CHARLES C. GAMBILL, contributor of "An Application of Radioisotope Wear Study Techniques," is a project engineer in the Research and Future Products Engineering Department of Frigidaire Division, Dayton, Ohio. Since 1955, he has been engaged in various developmental assignments in connection with future applications to Frigidaire products. Currently his work is concerned with uses of radioisotopes, of which he writes. Mr. Gambill also is an instructor in GM's ten-week study and laboratory program designed to familiarize GM engineers and scientists with radioactive isotopes and the techniques for their industrial application.

Mr. Gambill was graduated from Rose Polytechnic Institute in 1949 with the B.S. degree in mechanical engineering. He joined Frigidaire Division in 1950 as a testing engineer in the Commercial Engineering Testing Department. Later in the same year he was called to military duty and served until 1954 in the U.S. Air Force where he was a radar technician and instructor. He then attended Alabama Polytechnic Institute and was granted the degree of bachelor of electrical engineering in 1955. He returned to Frigidaire Division in 1955 as project engineer.

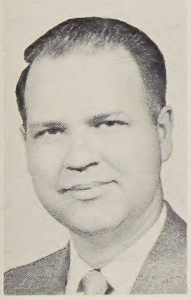
He is a member of Eta Kappa Nu, honorary electrical engineering society, and the Institute of Radio Engineers.

HARRY J. GILLILAND, co-contributor of "Magnetic Test Accurately Compares Heat Extraction Properties of Quenching Media," is a senior metallurgical engineer in the Process Development Section of the General Motors Process Development Staff, located at the GM Technical Center.

Prior to joining the Process Development Staff in 1955, Mr. Gilliland was supervisor in Manufacturing Development at the Kansas City plant of Buick-Oldsmobile-Pontiac Assembly Division. He joined B-O-P in 1951 as a metallurgical engineer in the Laboratory and Development Department.

Mr. Gilliland's current work is in metallurgical processing and development, including all phases of metal treating and fabrication. His recent projects have included work on the control of inclusions in aircraft steel forgings. Mr. Gilliland co-authored "Causes and Control of Distortion During Machining of Aluminum Alloy Forgings," which appeared in the January-February 1956 issue of the *General Motors Engineering Journal*.

Mr. Gilliland received the B.S. degree in metallurgical engineering in 1947 from the Missouri School of Mines and Metallurgy, Rolla, Missouri. He is a member of the American Society for Metals.



ROBERT W. GRAHAM, co-contributor of "New Servo Controlled Simulator Measures Vehicle Ride and Roll," is senior project engineer in the Passenger Car Chassis Section at the Chevrolet Motor Division Engineering Center, Warren, Michigan.

After receiving a B.S.M.E. degree from the University of Michigan in 1949, Mr. Graham joined the Detroit Transmission Division as a junior engineer in 1950. Before transferring to Chevrolet's engineering staff in 1953, he was in charge of experimental dynamometers at Detroit Transmission.

After beginning at Chevrolet as an experimental engineer, Mr. Graham was promoted to senior experimental engineer in 1954, and to his present position in January 1958.

Mr. Graham's most recent work has been in the design of air suspension for passenger cars. His previous work at Chevrolet has been in passenger car and truck development.

Mr. Graham is a member of the S.A.E., the Society for Experimental Stress Analysis, and the Instrument Society of America.

FARNO L. GREEN, contributor of "Studies of Radioisotopes Show Promise for Present and Future Applications in Engineering," is a senior research physicist in the Isotope Laboratory of the General Motors Research Staff, located at the GM Technical Center, Warren, Mich.

Mr. Green joined the Research Staff in 1956. In addition to his research in radioisotopes, he has served as a consultant for several Divisions of GM.

Mississippi College granted Mr. Green the B.A. degree with special distinction in mathematics and physics in 1941. He received the M.S. degree in physics from Louisiana State University in 1949, and has done advanced study toward a doctorate at the University of Tennessee.

Mr. Green's professional career has included educational work as head of the physics department at Wayland College, Plainview, Texas, and at Howard College, Birmingham, Alabama. Before joining General Motors, Mr. Green was a physicist at the Oak Ridge National Laboratory for four and one-half years working on cyclotron design, theory, and utilization. He was in charge of the 44-inch cyclotron program and nuclear physics applications using the 86-inch cyclotron for radioisotope production.

During the World War II period, Mr. Green spent five years of military service principally as communications officer with the Air Force in England, North Africa, Italy and Okinawa. He attained the rank of Major.

Mr. Green is a member of the American Physical Society and charter member of the American Nuclear Society. He has had papers published in *Nuclear Science and Engineering* and *IRE Transactions on Nuclear Science.*

ALLEN B. HAMILTON, contributor of "Mechanical Vibration Analysis by Electrical Circuit Analogy," is assistant chief structural engineer of the Structural Department at Elecro-Motive Division, La Grange, Illinois.

Mr. Hamilton joined Electro-Motive in 1942 as an engine tester after receiving a B.S.M.E. degree from the University of Michigan. In 1948, following assignments in the Electrical and Locomotive Test Departments, he was transferred to the Structural Calculations Department. His work with this Department included analyzing vibration problems, impact problems, and general structural designs dealing with such components as car body structures, Diesel engine parts, and electrical machinery.

In his present position, which he assumed in 1955, Mr. Hamilton is responsible for theoretical and experimental stress analysis and vibration problems. The Structural Department serves as a consulting group to the Engineering Department on special problems which arise during the design of such diverse components as car bodies, wheels and axles, air compressor drives, gears, piston rings, and motor armatures.

The technical affiliations of Mr. Hamilton include the Society for Experimental Stress Analysis. He is currently secretary of this Society's local section.

ELWOOD K. HARRIS, faculty member-in-charge for the typical General Motors Institute laboratory problem "Determine the Unbalanced Forces in a Converted V-8 Engine" and the solution appearing in this issue, is chairman of the Product Engineering Department at G.M.I. In this position he is responsible for correlating departmental assignments in the general areas of engineering drawing, descriptive geometry, thermodynamics, fluid mechanics, and chassis and transmission design. He also teaches internal combustion engine courses in applied design.

Mr. Harris joined General Motors in 1929 as an instructor in the Engineering Drawing Department at G.M.I. In 1940 he was made acting department head of the Product Engineering Department. He assumed his present position in 1946.

Michigan State University granted Mr. Harris a B.S.M.E. degree in 1929 and a M.E. degree in 1946. He is a member of the Society of Automotive Engineers and serves on various committees of this Society as a representative of student activities, including the National Student Committee.

DONALD E. HART, contributor of "What Is a Digital Computer?" is assistant department head of the Special Problems Department of the General Motors Research Staff, located at the GM Technical Center, Warren, Mich.

Mr. Hart joined the Special Problems Department as a college graduate-in-training in 1950. He was promoted to supervisor in 1953, and to his present position in 1954.

Currently, Mr. Hart is in charge of the Data Processing Group, which uses the IBM 704 Electronic Data Processing Machine. This group provides a complete computer service to General Motors. Mr. Hart previously spent two years developing computer hardware for information retrieval.

He received the B.E.E. and M.E.E. degrees from Rensselaer Polytechnic Institute in 1949 and 1950, respectively. At R.P.I. he attained membership in Sigma Xi and Tau Beta Pi.

Mr. Hart is the author of several published papers on computer orientation and application. He is a member of the I.R.E. and its Professional Group on Electronic Computers. He is also a member of the Association for Computing Machinery and the Institute of Management Sciences. Mr. Hart serves as chairman of the General Motors Committee on Engineering Computation.

BERTRAM A. SCHWARZ, co-contributor of "A Discussion of Some Factors Affecting Reproduced Radio Sound in an Automobile," is technical assistant to the general manager of Delco Radio Division. Prior to assuming his present position in 1957, Mr. Schwarz had been chief engineer of Delco Radio since 1936. His present responsibilities include supervision of projects dealing with research and development of automobile radios and components, transistors and other semi-conductors, and electronic apparatus, including communications for the military.

Prior to joining General Motors in 1936, Mr. Schwarz was chief engineer of the Automobile Radio Division of Zenith Radio Corporation and vice president in charge of engineering for Consolidated Industries, Limited, Toronto, Ontario.

Mr. Schwarz's work has resulted in the granting of more than 30 patents in the field of radio and electronics, tuning systems, and loudspeakers. He is a member of the Acoustical Society of America, a Fellow of the Institute of Radio Engineers, a member of the executive council of the Electronic Industries Association Engineering Department, and a director of the Kokomo Engineering Society.

RONALD E. SHAFER, co-contributor of "New Servo Controlled Simulator Measures Vehicle Ride and Roll," is a junior engineer in the Instrumentation Department of Chevrolet Motor Division's Engineering Laboratory, located at the Chevrolet Engineering Center, Warren, Michigan.

Mr. Shafer joined General Motors in 1956 as a college graduate-in-training with the Chevrolet Engineering staff. He was promoted to his present position of junior engineer in 1957.

Mr. Shafer currently is engaged in work involving servo systems and controls. He previously had participated in the applications of servo controls and servomechanisms to vehicle testing equipment, such as ride simulators. This testing equipment, with its advanced instrumentation, plays an important part in vehicle development.

Tri-State College granted Mr. Shafer the Bachelor of Science degree in 1956. He has co-authored a paper in the field of servo controls which has been presented before the Society of Automotive Engineers.

GEORGE H. STRICKLAND, contributor of "Organization and Function of the GM Patent Section," and coordinator of this issue's "Notes About Inventions and Inventors," is an assistant director of the Patent Section and also attorney-in-charge of the Dayton Office. He joined the GM Patent Section in 1929. Prior to that time he was a patent examiner in the U.S. Patent Office for five years.

From 1929 to 1951 Mr. Strickland handled patent matters dealing with Frigidaire Division products. In January 1952 he was named attorney-in-charge of the Patent Section's two Dayton Offices. The following year he coordinated the combining of these two Offices into the one Office now located at Frigidaire Division. He was named assistant director of the Patent Section in June 1952.

Mr. Strickland attended Harvard College and also George Washington University Law School, which granted him a bachelor of law degree in 1929. He is a member of the Bar of the District of Columbia and also the state of Ohio. He is a past president of the Dayton Patent Law Association.

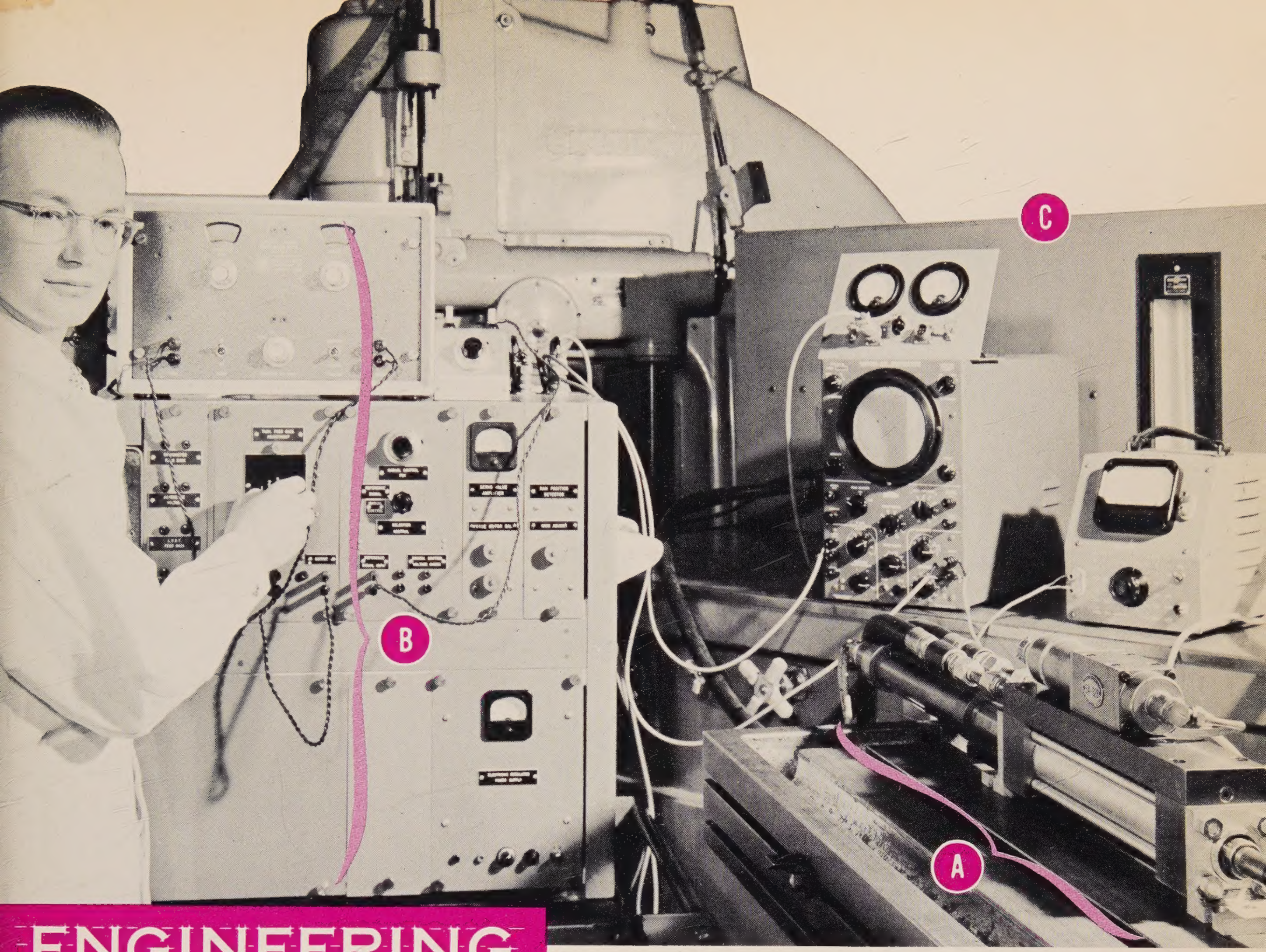
PAUL T. VICKERS, co-contributor of "Testing Paper Gas Turbines: Applying the Digital Computer to Engine Design," is supervisor of the Heat Transfer Section of the Engineering Development Department, General Motors Research Staff.

Mr. Vickers first joined General Motors in 1941 as a General Motors Institute co-op student sponsored by the Delco-Remy Division, Anderson, Indiana. After serving in the U.S. Army during World War II, he joined the Research Staff as a student, where he continued after his graduation from General Motors Institute in 1948 with a B.M.E. degree. At G.M.I. he was a member of Alpha Tau Iota honorary society.

Mr. Vickers presently is responsible for basic heat transfer studies, rotating regenerator development, applied thermometry, and applied heat transfer problems.

Before his promotion to supervisor in 1956, Mr. Vickers was project engineer on gas turbine cooling studies and piston cooling studies.

Mr. Vickers is a member of A.S.M.E., where he serves on the Gas Turbine Heat Transfer Committee, and the S.A.E.



ENGINEERING
ASSIGNMENT IN GM

Automatic controls for process machinery are required to control loads of high power level with considerable accuracy. Electric motors and similar electric output devices are unable to meet the stringent control accuracy required because of their high inertia and low response time. As a result high-performance, electro-hydraulic servomechanisms have been developed. For accurate control applications these servomechanisms provide the desired characteristics of high torque-to-inertia ratios, high speed response, great accuracy, smooth control, light weight, and compact size.

One phase in the developmental program of an electro-hydraulic servomechanism is devoted to performing evaluation tests to obtain performance data. In the accompanying photograph Glenn Wanttaja, senior project engineer in the Electronics Section of the GM Process Development Staff, is shown running a test to obtain frequency response characteristics of a servomechanism system. Similar tests are performed to obtain static and dynamic characteristics. Major components of the test setup are: *A*, force motor, hydraulic control valve, and load actuator; *B*, feedback transducer, feedback amplifier, and related test instrumentation; and *C*, the hydraulic power supply and test stand.

Mr. Wanttaja joined the GM Process Development Staff in 1950 as a college graduate-in-training after graduating from Michigan College of Mining and Technology with a B.S. degree in electrical engineering. The following year he was promoted to junior engineer and in 1953 was made project engineer at which time he began basic developmental work on servomechanisms. In his present position, which he assumed in 1955, he is responsible for further developmental work on servomechanisms and their application to process machinery.

After joining General Motors, Mr. Wanttaja continued his engineering education. He undertook graduate study and received a Master's degree in electrical engineering from Wayne State University in 1956.

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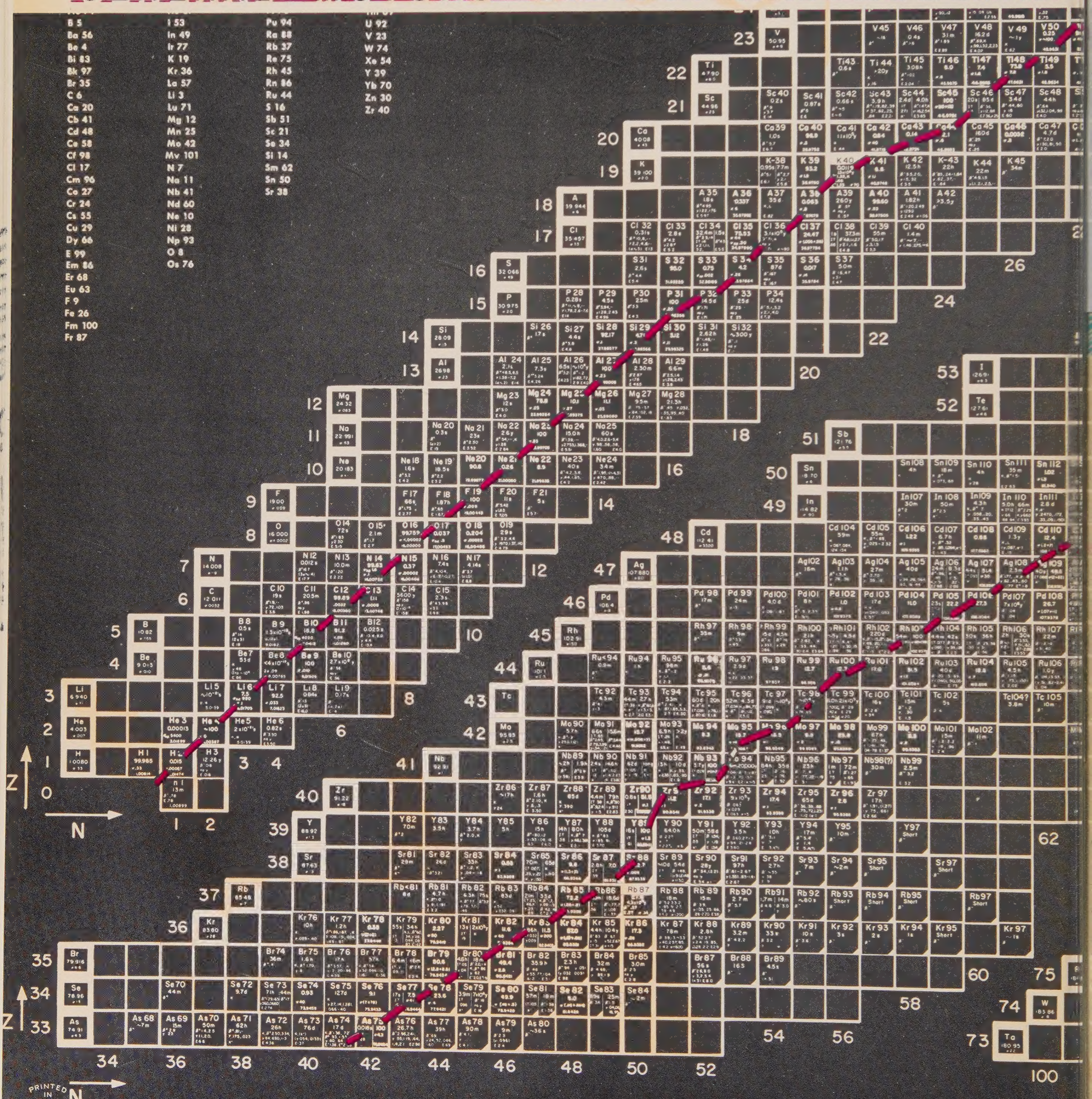

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